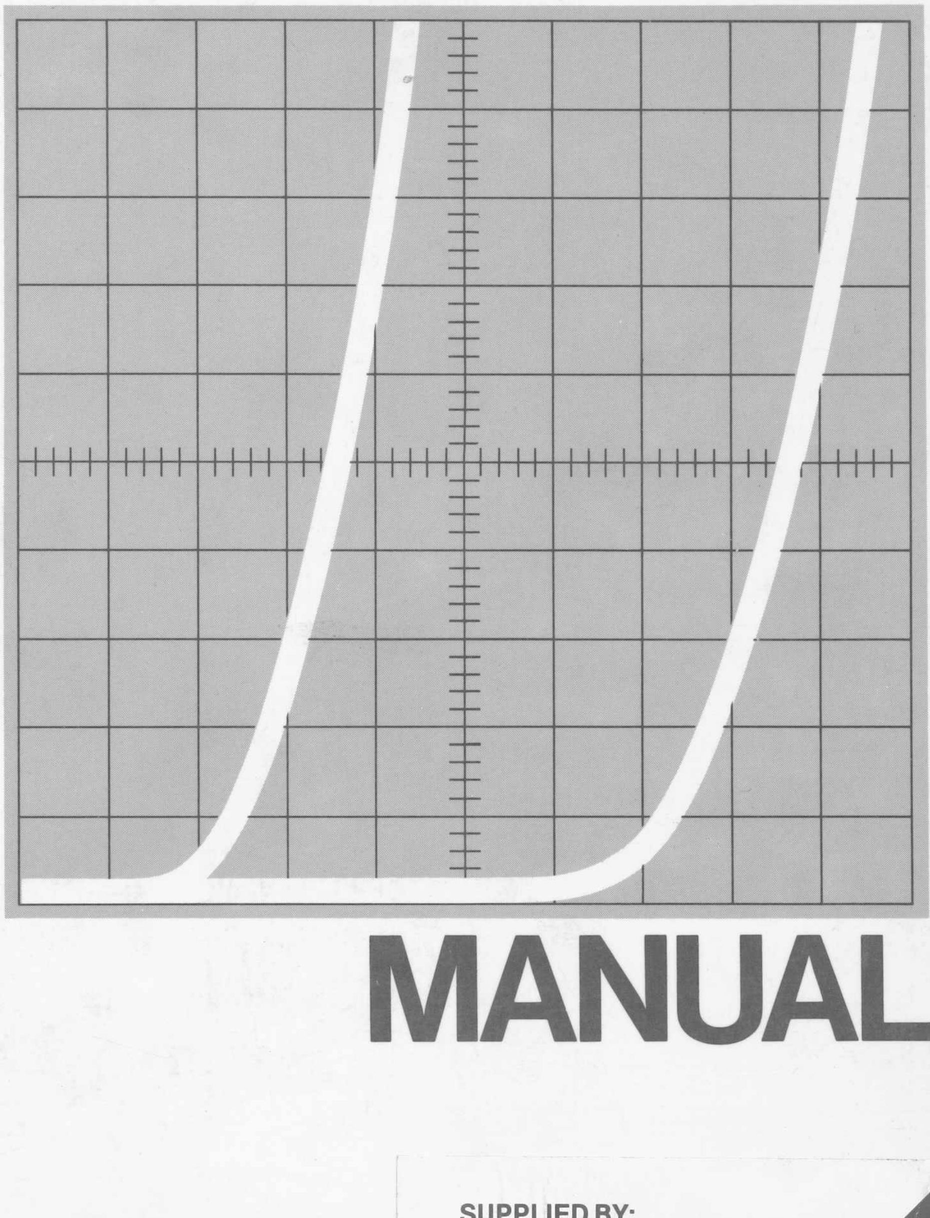
SILICON RECTIFIER



MANUAL

MOTOROLA

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MOTOROLA

SILICON RECTIFIER DATA MANUAL

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CHAPTER 1: BASIC ELECTRICAL CHARACTERISTICS OF DIODES

It is impossible for a manufacturer to specify and to characterize a rectifier diode under all conceivable conditions of use. However, having a sufficient background, the circuit designer can manipulate data sheet information sufficiently well to ensure satisfactory operation in a wide variety of applications. It is the purpose of this chapter to provide the necessary background. Therefore, the characteristics of an "ideal" diode will be examined and compared to those of a real diode.

IDEAL BEHAVIOR

An ideal diode would be one which completely blocks a voltage of one polarity, allows full current flow when a voltage of an opposite polarity is applied, and has no power loss. For purposes of this discussion, however, an ideal diode will be defined as a diode which has no reactive components and follows the voltage-current relationship predicted by the simple first-order theory as developed by Shockley.(1) This relationship is expressed by the following equations:

$$I_F = I_R \left(\epsilon^{\frac{q\phi}{kT}} - 1 \right) \tag{1a}$$

or

$$\phi = \frac{kT}{q} \ln \left(1 + \frac{I_F}{I_R} \right) \tag{1b}$$

where: I_F = forward junction current,

I_R = reverse junction current,

$\frac{kT}{q}$ = a common semiconductor constant* which equals 26 mV at 27°C (300°K),

ϕ = voltage across the junction.

A plot of these ideal diode characteristics is shown in Figure 1. The graph shows that any reverse voltage ($\phi = -V_R$) in excess of a few tenths of a volt produces a small reverse current which remains constant. When a forward voltage ($\phi = +V_F$) is applied, the forward current (I_F) increases exponentially. In order to create a diode having a low forward drop and a high reverse voltage capability, it is necessary for the semiconductor layer on one side of the junction to be highly doped with impurities (low resistivity) and the opposite layer to have high resistivity corresponding to a low doping level. Diode characteristics are determined primarily by the physical width and the level of impurities in the high resistivity region. If the p region is more heavily doped with impurities than the n region, the p region will have the greater number of current carriers and will be the emitter. In this

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* k = Boltzsmanns constant (1.38×10^{-23} joules/°K)
T = Absolute Temperature in °K
q = Electronic charge (1.6×10^{-19} coulombs)

instance, when a forward voltage is applied to the junction, the forward current consists mainly of holes that are injected from the p region (where they are plentiful) into the n region. In addition, there exists a small current flow of electrons from the lightly doped n region into the p layer. Conditions at the junction are depicted in Figure 2.

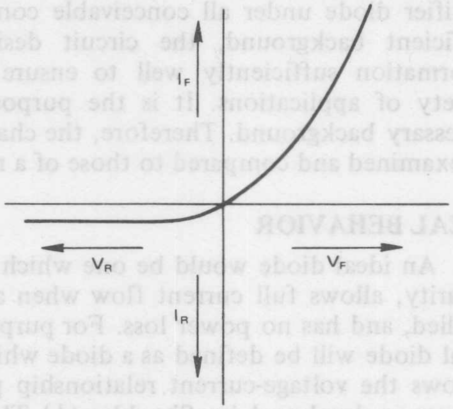
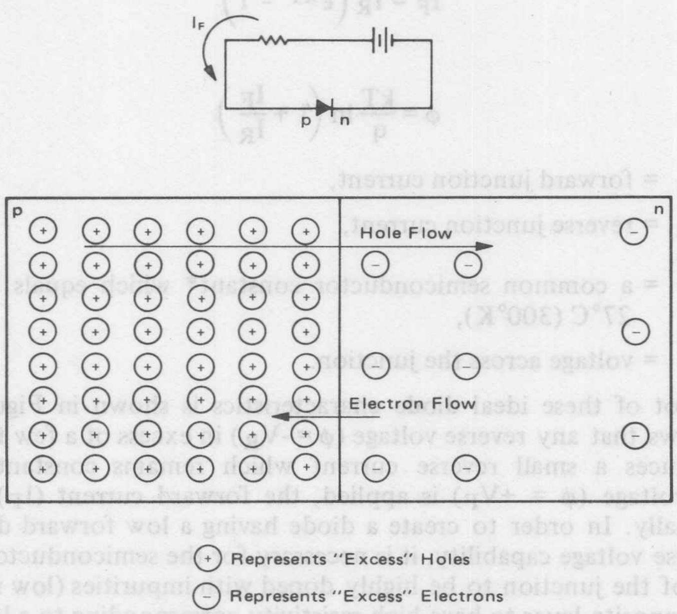


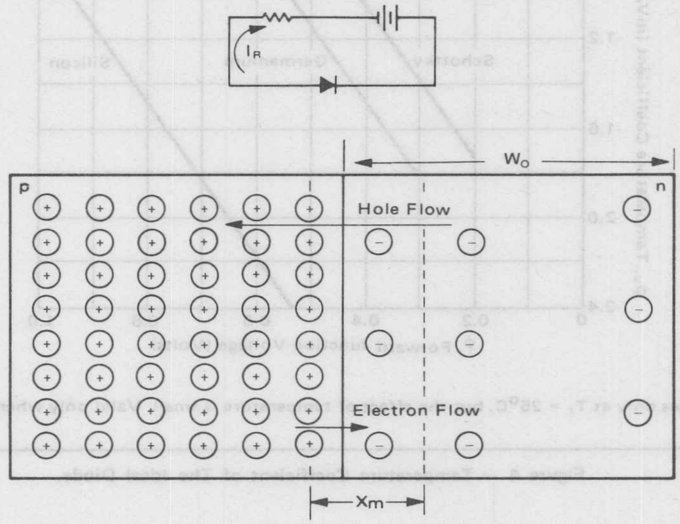
Figure 1 – Ideal Diode Characteristics



Length of arrows indicates relative amounts of hole and electron flow (current flow is actually uniformly distributed). "Excess" holes and electrons are those resulting from doping the pure material.

Figure 2 – Current Flow Under Forward Bias

When the junction is reverse-biased, the effect of the depletion layer must be considered. It arises because charges (holes in the p region, electrons in the n region) move away from the junction leaving exposed ions in a region near the junction, as indicated by Figure 3. In order to preserve charge neutrality, more area must be exposed on the high resistivity side of the junction, because the density of ions is less there than on the low-resistivity side. Consequently, the depletion layer exists principally in the high-resistivity side of the junction. The applied voltage appears across the depletion region; essentially no voltage drop occurs in the rest of the material. As voltage is raised, the depletion layer in a given device widens because the higher potential, which is of a polarity opposite to the impurities pulls them away from the junction.



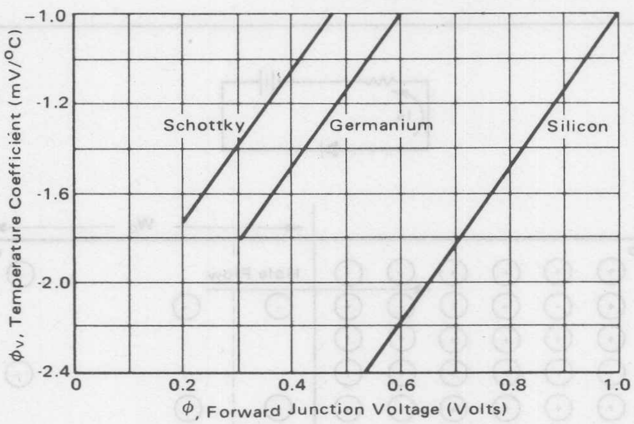
W_O = Physical Junction Width
X_m = Depletion Layer
Length of Arrows indicate relative amounts of hole and electron flow.

Figure 3 – Current Flow Under Reverse Bias.

The reverse current (I_R) consists mainly of those minority carriers* in the high resistivity region which are close enough to the junction to be swept across by the electric field. As resistivity is decreased or junction area reduced, I_R decreases as less minority carriers are available, also the forward drop at a given current increases with decreases in resistivity as V_F is related to I_R by Equation 1.

*Minority carriers are those of opposite polarity to that of the doping materials, i.e., holes in n type and electrons in p type. A more exact treatment of reverse current follows in the next section.

Although not apparent from Equation 1, temperature exerts a considerable influence upon the ideal diode characteristic. The diffusion current (I_R) roughly doubles for every 10°C increase in junction temperature, due to thermal agitation of the semiconductor molecules. Since Equation 1 is valid at all temperatures, V_F decreases (I_F being held constant) when I_R increases. The general "rule of thumb" used for the temperature coefficient of V_F is -2.0 mV/°C; the exact value depends upon the forward drop of the junction[2] which is dependent upon the forward current and the diode area, resistivity, and material. Figure 4 shows temperature coefficient behavior.



Data applies only at T_J = 25°C, but the effect of temperature is small. Valid only when $\epsilon^{q\phi/KT} >> 1$.

Figure 4 – Temperature Coefficient of The Ideal Diode.

REAL DIODE BEHAVIOR

There are a number of reasons why real diodes do not follow the ideal equations. Rather than complicate the equations, some effects are generally shown graphically while others can often be depicted by constructing a model or equivalent circuit for the diode.

Leakage Current – Whenever a semiconductor p-n junction is reverse biased, a reverse or leakage current (I_R) follows through the junction. The reverse current is the sum of three currents: I_D, due to diffusion, I_G, due to charge generation and I_S, due to surface leakage. Therefore,

$$I_R = I_D + I_G + I_S. \quad (2)$$

The behavior of each of these components of reverse current will be considered separately. The "ideal diode" equation assumes I_G and I_S are negligible.

The diffusion current (I_D) is caused by minority carriers in the high resistivity region, which come under the influence of the high field across the depletion layer and are pulled across the junction. The diffusion current is strongly dependent upon temperature and is constant with voltage only in

junctions in which the high resistivity side is very wide. Since wide, high-resistivity regions are a source of voltage drops, the width is minimized in most devices, and a dependence upon voltage is observed. An analysis of the p-n junction shows that the reverse current is inversely proportional to the electrical or effective junction width of the high resistivity side (W), which is given as:

$$W = W_0 - x_m \tag{3}$$

where: W = the effective junction width,

W_0 = the physical junction width,

x_m = the depletion-layer thickness.

The depletion layer thickness (x_m) varies as the n'th root of applied voltage, depending upon the type of junction; i.e., $x_m \propto \sqrt[n]{V}$. The value of n is 2 for a step junction typical of the alloy process, and is generally close to 3 for a graded junction typical of the diffused process. The ideal diode equation can be modified to include the fact that I_D is proportional to W; the equation shown on Figure 5 is the result. Not only does a finite slope appear on the reverse characteristic, but, as the voltage becomes large, the current increases quite rapidly as the junction width becomes extremely small.

As previously discussed, the depletion layer exists primarily on the high-resistivity side of the junction. For a given applied voltage, the higher the resistivity, the wider is the depletion layer. If the high-resistivity region is fairly narrow, it is possible for the depletion layer to extend entirely through the high-resistivity side of the junction. At this point, diode action ceases and any voltage change at one side of the diode is observed at the other. This phenomena is called punch-through or reach-through.

The diffusion current is the dominant leakage current in germanium and Schottky devices, particularly at high temperatures. However, in silicon

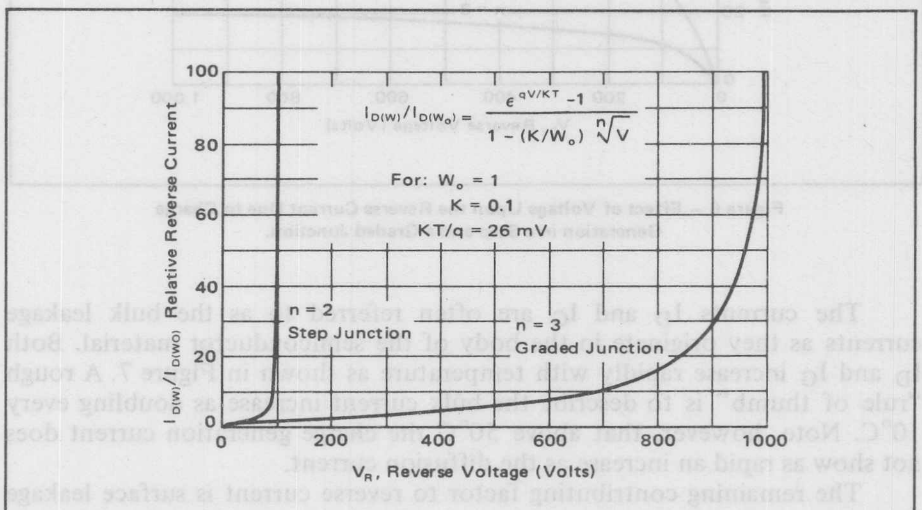


Figure 5 — Effect of Voltage Upon the Reverse Current Due to Diffusion in a Step and a Graded Junction.

p-n junction devices the charge generation current I_G, due to impurity ions in the depletion layer, is the dominant temperature-sensitive current. It is proportional to the width of the depletion layer and is given by:

$$I_G = K_V K_I \sqrt[n]{V} \qquad (4)$$

where: I_G = charge generation current,

K_V = an empirical factor which approaches unity for voltages greater than 0.1 volt,

K_I = a proportionality constant determined primarily by geometry, resistivity, and the impurities in the depletion layer,

V = applied voltage,

n = exponent describing depletion layer behavior.

Figure 6 shows the behavior of the charge generation current with voltage which is quite different from that of the diffusion current shown in Figure 5. In particular, the slope is higher in the low voltage region and it follows a power law for all voltages above 0.1 volt.

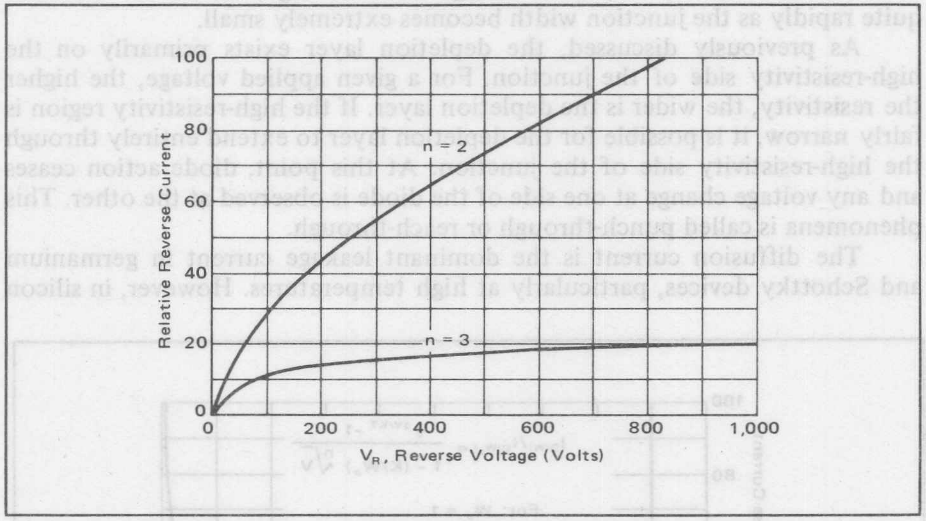


Figure 6 — Effect of Voltage Upon the Reverse Current Due to Charge Generation in a Step and a Graded Junction.

The currents I_D and I_G are often referred to as the bulk leakage currents as they originate in the body of the semiconductor material. Both I_D and I_G increase rapidly with temperature as shown in Figure 7. A rough "rule of thumb" is to describe the bulk current increase as doubling every 10°C. Note, however, that above 50°C the charge generation current does not show as rapid an increase as the diffusion current.

The remaining contributing factor to reverse current is surface leakage (I_S). The surface leakage current may be considered as resulting from a resistance path across the junction. Consequently, the value of I_S is voltage dependent, but voltage and current are not linearly related. At high voltages, I_S can add considerably to the total reverse current. Surface leakage often

increases with temperature but it is not predictable; it is generally much less temperature sensitive than the bulk currents.

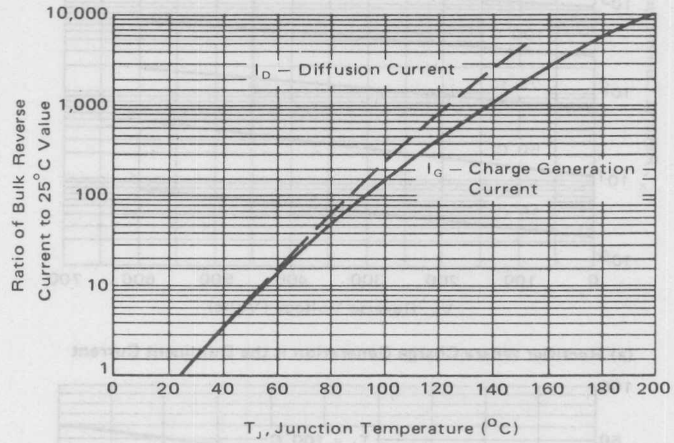
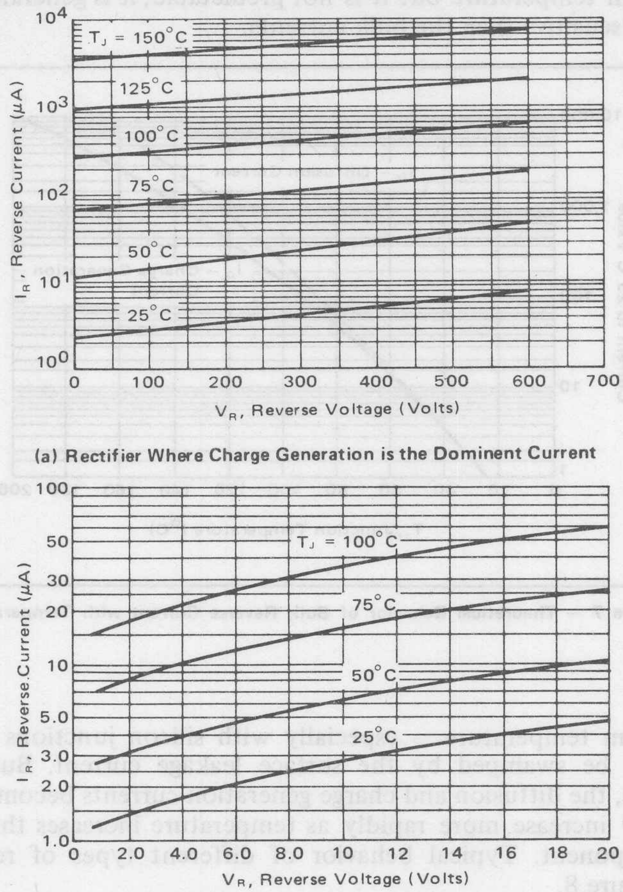


Figure 7 – Theoretical Behavior of Bulk Reverse Current with Temperature.

At room temperature – especially with silicon junctions – the bulk current may be swamped by the surface leakage current. But, at higher temperatures, the diffusion and charge generation currents become dominant because they increase more rapidly as temperature increases than does the surface component. Typical behavior of different types of rectifiers are shown in Figure 8.

Voltage Breakdown – As the reverse voltage applied to a diode is increased, the current flow increases. When the voltage approaches a level called the avalanche breakdown voltage (V_B), the current increases without limit.

Behavior of various materials are shown in Figure 9. Note that the reverse current has doubled at a reverse voltage approximately 80 to 90% of the breakdown voltage and the current increases rapidly with further increases in voltage above those points. The higher the resistivity of the high-resistivity side of the junction, the higher the avalanche breakdown voltage will be. Figure 10 shows the relationship for the various materials in common use. Avalanche breakdown is attributed to the fact that the high field across the depletion layer accelerates any moving particle, which, if moving fast enough, may have sufficient energy to free additional particles by collision with atoms. Therefore a multiplication of carriers occurs which proceeds at an ever-increasing rate as the breakdown voltage is approached. Avalanche breakdown occurs within the bulk of the material. Surface breakdown may also occur, but it is not predictable by any simple analytical means. The punch-through voltage mentioned in the previous section is not a problem in the type of diodes used in power applications, as these diodes are designed so that avalanche breakdown takes place well below punch-through.



(a) Rectifier Where Charge Generation is the Dominent Current

(b) Shottky Rectifier Where Diffusion is the Dominant Current

Figure 8 — Effect of Reverse Voltage on Reverse Current

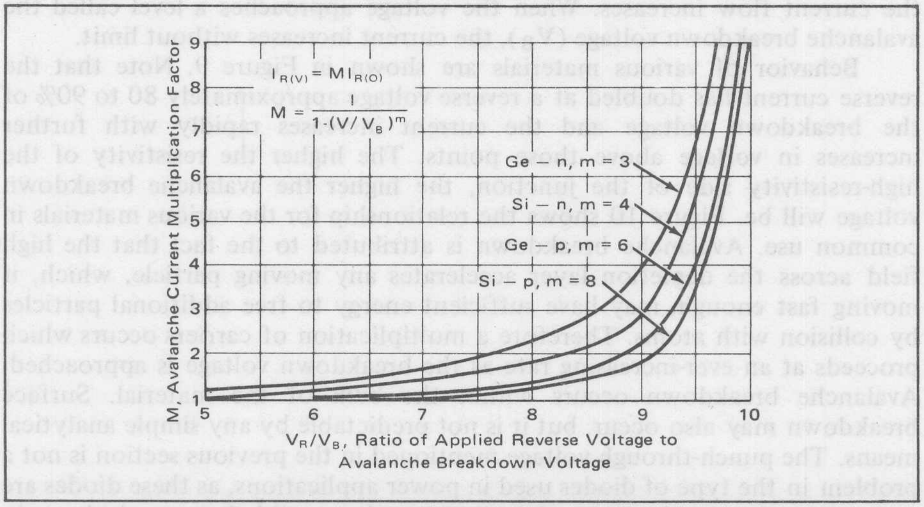


Figure 9 — Avalanche Current Multiplication Factor (Applies to Bulk Currents Only)

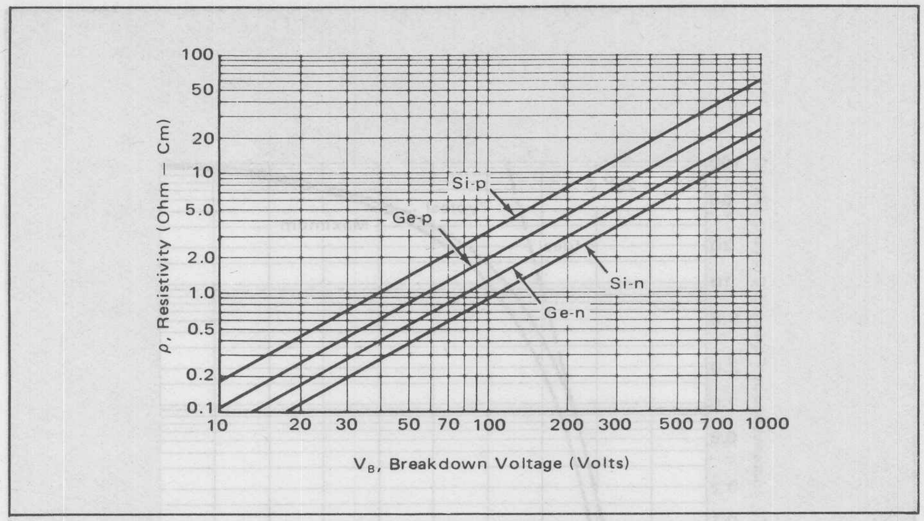


Figure 10 – Bulk Resistivity of the Basic Semiconductor Materials as Related to Avalanche Breakdown Voltage For a Step Junction. A graded (diffused) junction has higher breakdown.

Forward Voltage Drop – The passage of current through a diode will produce a voltage drop across the bulk resistance which is not accounted for by Equation 1. This resistance is given by the familiar:

$$R = \frac{\rho l}{A} \tag{5}$$

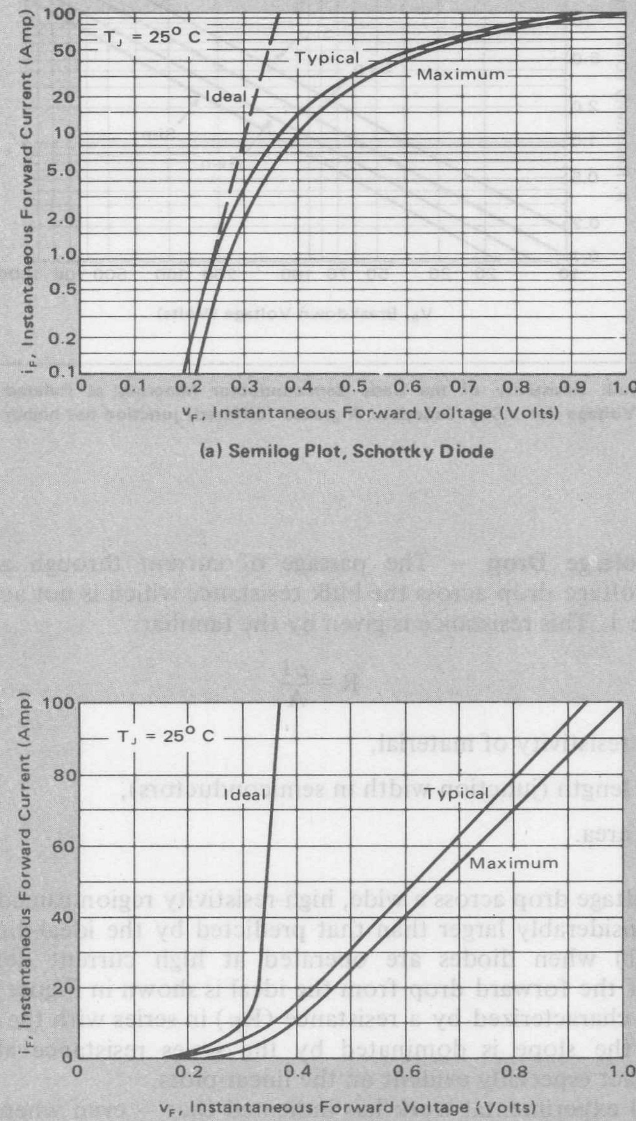
where: ρ = resistivity of material,

l = length (junction width in semiconductors),

A = area.

The voltage drop across a wide, high-resistivity region can add a voltage, which is considerably larger than that predicted by the ideal-diode formula (Equation 1) when diodes are operated at high current densities. The departure of the forward drop from the ideal is shown in Figure 11, and can be partially characterized by a resistance (R_F) in series with the ideal diode. Note how the slope is dominated by the series resistance above a few amperes, a fact especially evident on the linear plots.

Careful experimental work has indicated that – even when the voltage drop caused by the resistivity of the semiconductor material is considered – a departure from the ideal relationship exists.(3) The forward voltage-current characteristic is found to be incrementally exponential; however, the exponent is $q\phi/\lambda KT$, where λ is a number which varies from 1 to 2. At moderate current densities, $\lambda = 1$; as current density increases, λ approaches 2.(4) In silicon p-n junctions another departure from the ideal occurs at very low current densities where forward current is dominated by current flow due to carrier recombination and generation in the depletion region,(5) and the V-I characteristic is described by making λ approach 2 as current



(a) Semilog Plot, Schottky Diode

(b) Linear Plot, Schottky Diode

Figure 11 — Comparison of the Forward Drop of an Ideal and a Real Diode.

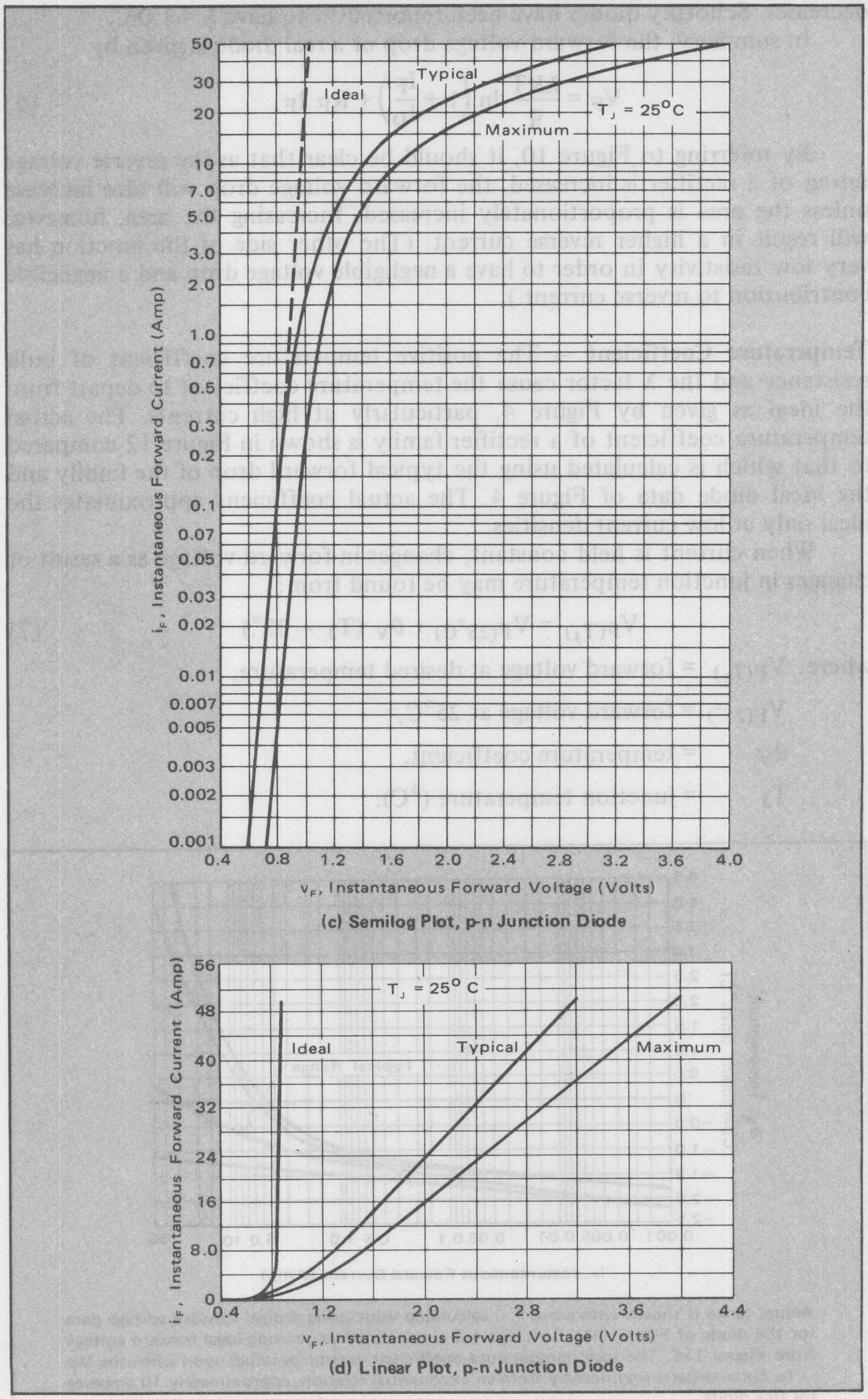


Figure 11 – Comparison of the Forward Drop of an Ideal and a Real Diode. (Continued)

decreases. Schottky diodes have been reported[6] to have $\lambda = 1.06$.

In summary, the forward voltage drop of a real diode is given by

$$V_F = \frac{\lambda KT}{q} \ln\left(1 + \frac{I_F}{I_D}\right) + R_F\, I_F \tag{6}$$

By referring to Figure 10, it should be clear that as the reverse voltage rating of a rectifier is increased, the forward voltage drop will also increase unless the area is proportionately increased. Increasing the area, however, will result in a higher reverse current. (The other side of the junction has very low resistivity in order to have a negligible voltage drop and a negligible contribution to reverse current.)

Temperature Coefficient – The positive temperature coefficient of bulk resistance and the λ factor cause the temperature coefficient to depart from the ideal as given by Figure 4, particularly at high currents. The actual temperature coefficient of a rectifier family is shown in Figure 12 compared to that which is calculated using the typical forward drop of the family and the ideal diode data of Figure 4. The actual coefficient approximates the ideal only at low current densities.

When current is held constant, changes in forward voltage as a result of changes in junction temperature may be found from:

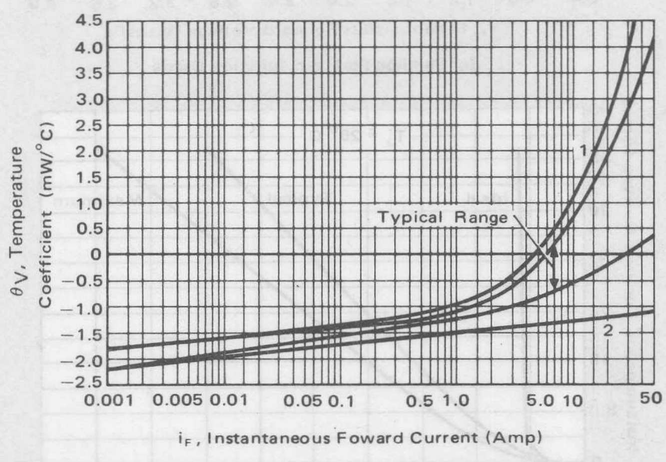
$$V_{F(T_J)} = V_{F(25°C)} + \theta_V\,(T_J - 25°) \tag{7}$$

where: $V_{F(T_J)}$ = forward voltage at desired temperature,

$V_{F(25°)}$ = forward voltage at 25°C,

θ_V = temperature coefficient,

T_J = junction temperature (°C).



Actual range is shown with curve 1 – calculated value using typical forward voltage data for the diode of Figure 11C – and curve 2 – calculated value using ideal forward voltage from Figure 11C. The ideal temperature coefficient cannot be relied upon when the V_F – I_F curve departs significantly from an exponential relation, approximately 10 amperes for this diode.

Figure 12 – Temperature Coefficient of Forward Voltage for a Family of Real Diodes.

When using Equation 7, it is overly conservative to use worst case values because a correlation exists between θ_V and V_F. At high currents where V_F departs from its exponential relation to I_F, a corresponding departure occurs between θ_V and I_F caused by the bulk resistance of the semiconductor material. In practice, therefore, the temperature coefficient given by the upper curve of Figure 12 will be associated with diodes having the maximum forward drop at currents above the neck between the curves (0.5 A for the rectifiers of Figure 12).

Below 0.5 A the correlation between I_F and θ_V is the opposite; that is, the diodes with maximum forward drop have the maximum (most negative) temperature coefficient in keeping with the ideal relationship of Figure 4.

Capacitance – The fact that oppositely charged particles are close to each other at the junction results in a capacitive effect (transition capacitance) similar to that of a parallel-plate capacitor. Stray capacitance introduced by the case, (C_C,) is also present. High resistivity materials result in a wider depletion layer at a given voltage than lower-resistivity materials and, thus, have a lower capacitance per unit area. Since increasing the reverse voltage causes the depletion layer to widen, the capacitance decreases. Figure 13 shows these effects.

Total capacitance, (C_T) generally follows the relationship shown below:

$$C_T = C_C + \frac{C_O}{\left(1 + \frac{V_R}{\phi_O}\right)^n} \tag{8}$$

where: C_C = the case capacitance,

C_O = junction capacitance at $V_R = 0$,

ϕ_O = junction "contact" potential (approximately 0.6 V),

n = exponent governing depletion layer widening effects. It is usually 1/3 for rectifiers.

As the data shows, the relationship can be stated approximately as

$$C_T = k / (V_R)^n. \tag{9}$$

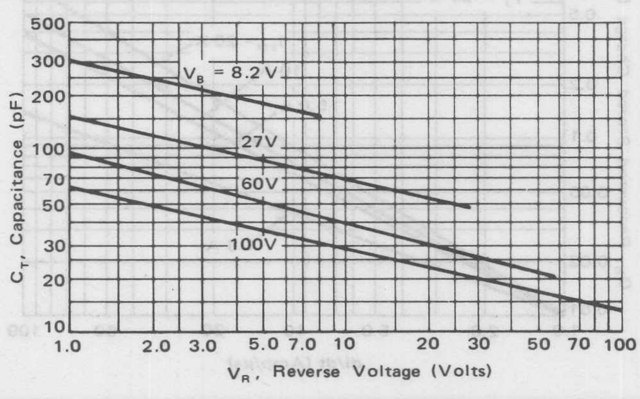
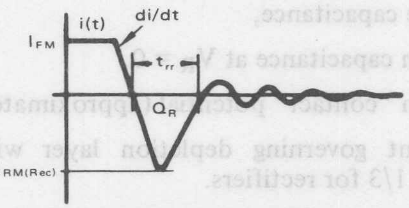


Figure 13 – Effect of Voltage and Resistivity (as evidenced by voltage breakdown) Upon Capacitance for a Small Junction Diode.

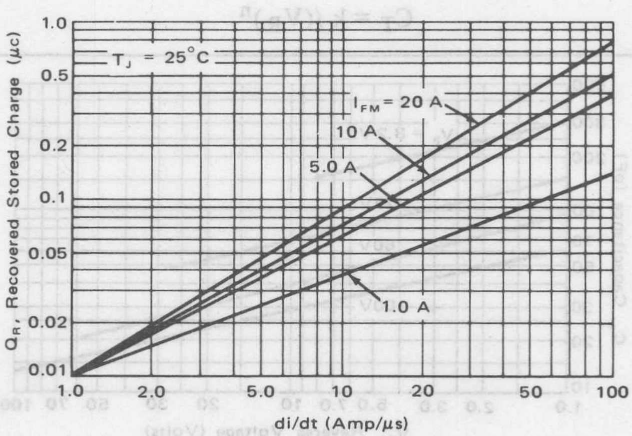
Transition capacitance is more directly a function of the impurity concentration; nothing else but junction voltage affects it. Therefore C_T is constant with temperature until the temperature is so high that the thermally generated carriers are comparable in number to the carrier concentration introduced by the semiconductor doping. Above that temperature the capacitance increases, as the impurity concentration is effectively increasing.

Capacitance is of little significance in most power rectifier applications, but it is significant in Schottky rectifiers at high frequencies because the Schottky device does not exhibit reverse and forward recovery transients, as described in the following sections.

Charge Storage – Another important mechanism in real p-n junction diodes is charge storage. When a forward current is flowing, a carrier gradient is produced in the high resistivity side of the junction resulting in an apparent storage of charge. If the source of forward bias is suddenly changed to a reverse bias, the stored charge maintains a current flow (now a reverse current) until the charge is depleted by a combination of reverse current flow and internal recombination. Thus, the phenomenon of storage or reverse recovery time is another departure from an ideal diode. The recovery time becomes less of a problem as forward current is reduced, since the gradient producing these excess carriers is less, resulting in less stored charge.



(a) Reverse Recovery Waveform



(b) Recovered Stored Charge Data

Figure 14 – Recovery Waveform and Stored Charge Data for a Fast Recovery Rectifier.

Also, an increase of reverse bias will hasten the depletion of the stored charge since more recombination charge is made available.

Making diodes from materials having a low lifetime (time that an isolated charge can exist before recombination) results in less recovery time as internal recombination proceeds faster. Lifetime decreases as resistivity decreases because more recombination centers exist, due to a higher level of impurities. Certain impurities such as gold can be introduced into the diode where they are effective as lifetime "killers". Unfortunately, these impurities also act as generation centers and, therefore, cause an increase in the charge generation component of reverse leakage current.

Calculation of recovery time under an arbitrary set of conditions is a difficult, if not an impossible, task. However for fast recovery rectifiers, a technique based upon recovered stored charge and commutation *di/dt* has been developed.(7) Recovered stored charge is the amount of charge which appears in the circuit; the charge is the area under the reverse recovery transient waveform. (See Figure 14a). Typical charge data is shown in Figure 14b. Commutation *di/dt* is the rate of change of current from the forward current level to the reverse current peak. For a given forward current and *di/dt*, the stored charge can be found and used in the equations below to calculate reverse recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(Rec)}$).

$$t_{rr} = 1.41\left(\frac{Q_R}{di/dt}\right)^{1/2} \tag{10}$$

$$I_{RM(Rec)} = 1.41\,[Q_R(di/dt)]^{1/2} \tag{11}$$

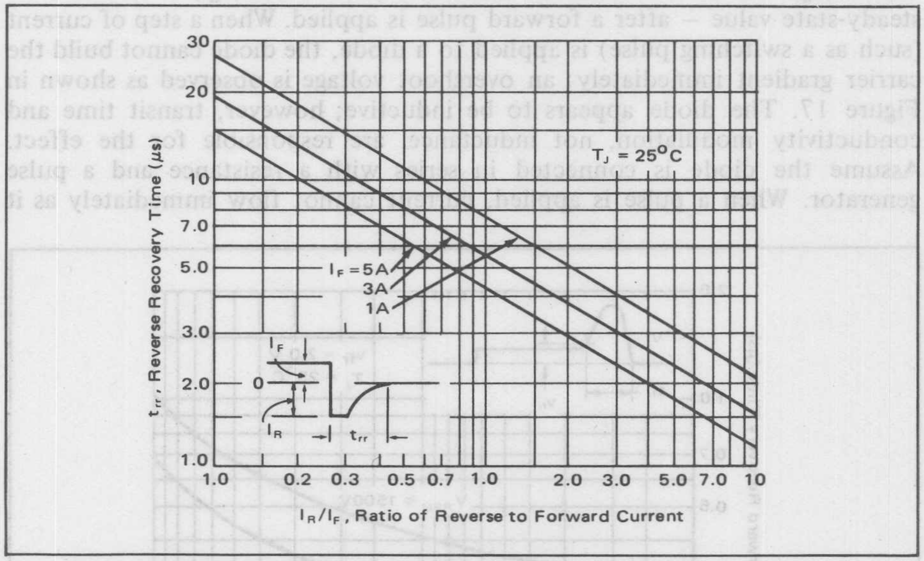


Figure 15 – Behavior of Reverse Recovery Time in a 25 Amp Low Frequency Rectifier

A more traditional way of describing the reverse recovery behavior is to test under conditions of a constant current source. The resulting waveforms and typical data are shown in Figure 15. Note that the ratio of forward to reverse current is the primary factor influencing the recovery time.

Stored charge and reverse recovery time increase with temperature. Typical behavior is shown in Figure 16. Stored charge decreases with the forward current pulse width when it is less than a few times the maximum value of t_{rr}.

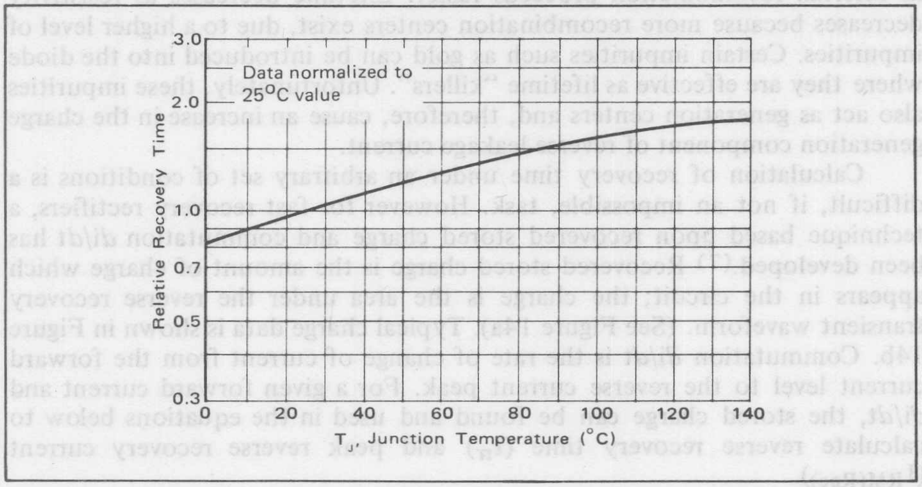


Figure 16 – Effect of Temperature Upon Reverse Recovery Time

Forward Recovery – A final undesirable property of real diodes is forward recovery time, t_{fr}. Forward recovery time is defined as the time required for the voltage across the diode to reach a defined level (v_{fr}) – close to its steady-state value – after a forward pulse is applied. When a step of current (such as a switching pulse) is applied to a diode, the diode cannot build the carrier gradient immediately; an overshoot voltage is observed as shown in Figure 17. The diode appears to be inductive; however, transit time and conductivity modulation, not inductance, are responsible for the effect. Assume the diode is connected in series with a resistance and a pulse generator. When a pulse is applied, current cannot flow immediately as it

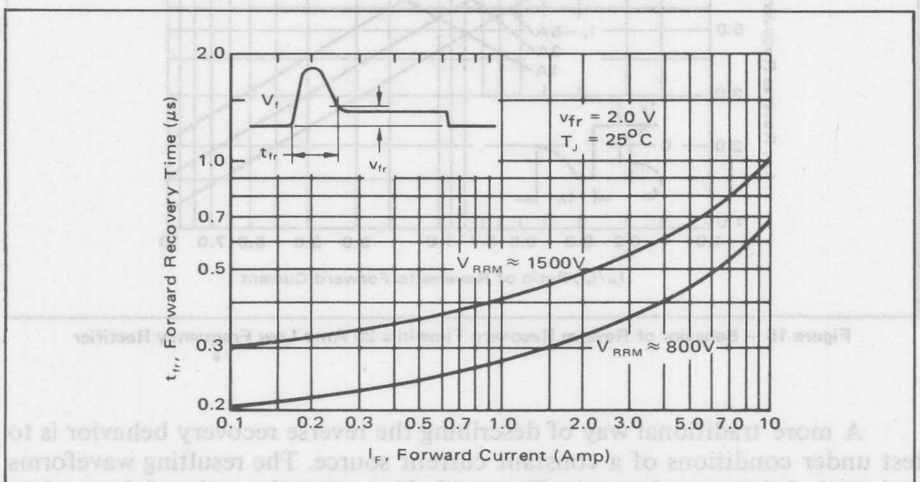


Figure 17 – Forward Recovery Waveform and Typical Recovery Behavior for a Small Diode.

takes a finite time (transit time) for carriers to cross the junction and build up the charge gradient; therefore, the voltage across the diode could equal the applied voltage. In practice, it usually does not because the junction capacitance and the rise time of the applied pulse slow the rate of voltage rise across the diode. As carriers begin to cross the junction, they build up the charge gradient and also cause an apparent decrease in the resistivity, which is observed as a decreasing voltage as time increases. Schottky diodes do not exhibit forward recovery time as they do not build up a minority carrier gradient and are made of low resistivity material.

To obtain higher voltage breakdown, higher resistivity material is required. Consequently, high voltage parts have longer forward recovery times. See Figure 17.

Waveform Efficiency – Rectifiers are characterized principally for use at 60 Hz and current derating data is valid generally only at 60 Hz. At higher frequencies – above a few kHz for standard rectifier diodes – the transient response of the diode must be taken into account. A direct method of doing this is to measure the rectification efficiency which is defined as

$$\eta = \frac{P_{DC(Out)}}{P_{AC(In)}}. \tag{12}$$

Meters which measure true rms power regardless of the system impedance and the waveform and frequency of the signal are non-existent; hence, a technique was developed in which a true rms voltmeter and a dc voltmeter could be used. By ignoring the power loss in the diode, from Equation 12 the waveform efficiency (often called rectification ratio or conversion efficiency) may be written in terms of input voltage (V_I) and output voltage (V_O) as:

$$\sigma = \frac{\dfrac{V^2_{O(DC)}}{R_L}}{\dfrac{V^2_{I(RMS)}}{R_L}} = \frac{V^2_{O(DC)}}{V^2_{I(RMS)}}. \tag{13}$$

Since the diode is assumed lossless, the rms input voltage equals the rms output voltage. Hence:

$$\sigma = \frac{V^2_{O(DC)}}{V^2_{O(RMS)}} \tag{14}$$

Since the square of an rms voltage is equal to the sum of the squares of its components, Equation 14 may be written as

$$\sigma = \frac{V^2_{O(DC)}}{V^2_{O(AC)} + V^2_{O(DC)}} \tag{15}$$

Therefore, waveform efficiency may be measured by use of a dc meter and a true rms ac meter.

For a square wave input signal of peak amplitude V_M varying positive and negative with respect to ground, $V_{0(DC)} = V_M/2$ and $V_{I\ (RMS)} = V_M$.

Substituting in Equation 13, σ is found to be 0.5 (or 50%). For a full wave circuit the opposite polarity half of the input will be used thereby doubling the efficiency. As the input frequency is raised, the diode will conduct appreciably into the negative half cycle which lowers the average or dc voltage output.

For a sine wave input, the situation is similar except that the maximum theoretical efficiency is less. $V_{O(DC)} = V_M/\pi$ and $V_{O(RMS)} = V_M/2$; substituting into Equation 14, σ calculates to be $\pi/4$ = or 40.6%. Typical measured data is shown in Figure 18. The data has also been normalized to the maximum theoretical values of 50% and 40.6% for square and sine wave input voltage, respectively. The data may be used to predict the approximate drop in output voltage caused by the diode transient response by using the relationship of Equation 13; i.e., $V_0 = V_I \sqrt{\sigma}$ (normalized). For example, a dc-to-dc converter designed to produce 100 V_{DC} (by neglecting the transient response of the diode) would have an output voltage of 100 $\sqrt{0.78}$ or approximately 88 volts at 20 kHz, using the 175°C square wave data of Figure 18.

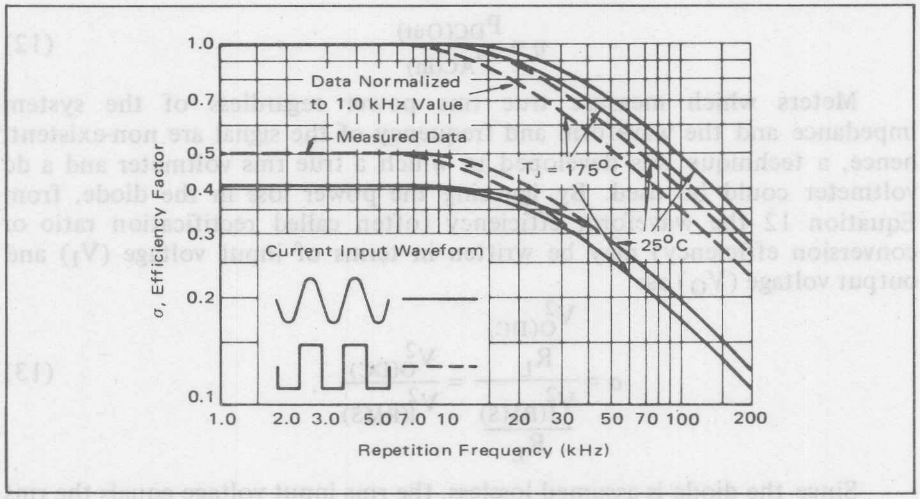


Figure 18 – Rectification Waveform Efficiency

Rectification efficiency data cannot be used to predict power losses in the diode. To date, no satisfactory analytical approach has been devised. The problem is not severe with half-wave circuits with resistive loads and is of moderate concern with capacitive input filters. Full-wave and bridge circuits should be avoided at frequencies where efficiency is low; they pose an acute problem because during reverse recovery time two conducting diodes are placed in series directly across the input. If used, commutating current and power dissipation will have to be found experimentally and steps taken to hold the commutating current to an acceptable level.

DIODE MODEL

These various properties of real diodes (resistance, capacitance, voltage breakdown, charge storage, etc.) can be added to the ideal diode as external elements to get the equivalent circuit shown in Figure 19.

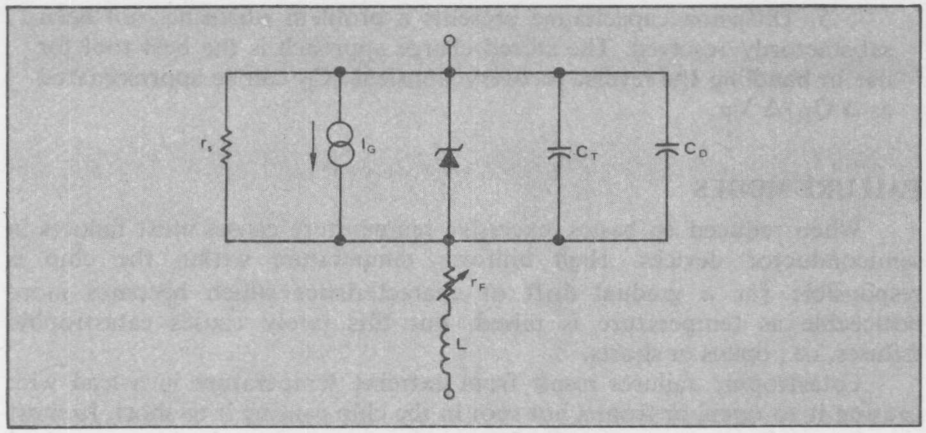


Figure 19 – Equivalent Circuit of a Diode

The diode, which follows Equation 1 (when modified by λ) is given the avalanche or zener symbol as a reminder that it has a voltage limit, V_B. The series resistance, r_F, is shown as variable to partially account for forward recovery time; it also accounts for forward voltage drop. The resistor r_s represents the surface component of the reverse current and is also generally used to account for changes in bulk current with voltage. I_G is the charge-generation current generator.

Capacitor C_T represents the transition capacitance. The diffusion capacitance C_D partially accounts for the forward recovery effect because it is a measure of carrier transit time. L is also generally required to account for t_{fr}. C_D also accounts for storage and turnoff time. C_D does not behave like a normal capacitor; its value is proportional to the value of forward current. When a reverse current is applied to the diode, C_D, unlike an ordinary capacitor, holds the voltage roughly constant until most of its charge is dissipated. The amount of charge remaining on C_D when it ceases to maintain fixed voltage depends greatly on the physical construction of the diode. For Schottky diodes, $C_D = 0$.

The model can be fitted to measured diode data by using the following as a guide:

1. Forward Data is plotted over the current range of interest. Junction temperature must be constant. From a linear plot, the steady state value of r_F is easily deduced. By using curve fitting techniques, values of λ and I_D can be found such that Equation 6 describes forward behavior.

2. At the same junction temperature as above, plot I_R vs. V_R. The slope yields a suitable value for r_s (avalanche and depletion layer effects affect the slope but are accounted for by r_s rather than complicating the mathematics). Find a value for I_G such that Equation 2 is satisfied.

3. From a measured forward recovery waveform choose values of L and r_F to fit the curve to a standard L/R response. r_F will decrease somewhat as i_F builds up to its steady state value.

4. Capacitance C_T is measured directly under reverse bias and fitted to Equation 8 or 9 depending upon the accuracy desired. Equation 8 describes behavior better near the zero bias region.

5. Diffusion capacitance presents a problem which has not been satisfactorily resolved. The stored charge approach is the best tool for use in handling the reverse recovery transient. C_D can be approximated as $\Delta Q_R / \Delta V_F$.

FAILURE MODES

When reduced to basics, excessive temperature causes most failures in semiconductor devices. High uniform temperature within the chip is responsible for a gradual drift of characteristics which becomes more noticeable as temperature is raised, but this rarely causes catastrophic failures, i.e., opens or shorts.

Catastrophic failures result from extreme temperature in a lead wire causing it to open, or from a hot spot in the chip causing it to short. In most circuits, the latter also causes the former. A reverse voltage is always required in order to produce a sufficient amount of current crowding to cause a hot spot, and high hot-spot temperatures cause an extreme reduction in the voltage capability of a semiconductor. (In other words, a thermally induced breakdown, observable on a V-I plot, occurs: See Figure 20.)

Thermal breakdown – a switch back of voltage from a high to low level – has been shown[8] to be a fundamental property of any semiconductor material. It occurs at the temperature at which the material becomes intrinsic.* The temperature of intrinsic conduction is inversely related to resistivity, varying from 200°C to 400°C for resistivity values in common use.

The most thermally rugged devices are silicon, diffused-junction or Schottky barrier semiconductors of low resistivity. Silicon is better than germanium because it becomes intrinsic at higher temperatures, the diffused junction results in more even current distribution than does the alloy, and lower resistivity material becomes intrinsic at higher temperatures than high-resistivity material.

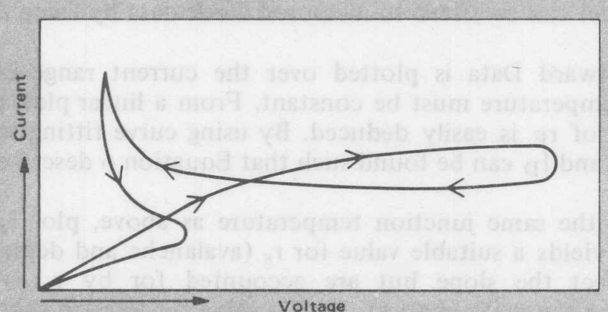


Figure 20 – Typical V-I Plot of Semiconductor Material Exhibiting Thermal Breakdown

*A material is said to be intrinsic when the electron-hole pairs caused by thermal agitation approximate those caused by intentional doping of the crystal.

TRADEOFFS

The effect of resistivity on rectifier characteristics has been discussed throughout this chapter. All characteristics are directly or inversely proportional to area; the width of the anode region also plays a part. The interplay between characteristics is shown in Table 1.

Physical Change	Electrical Change	
	Increase	Decrease
Increase anode resistivity	$r, V_B, I_D, L, \phi, r, C_D$	C_T
Increase junction area	C_T, C_D, I_D, I_G	r, ϕ
Increase width of anode region	r, V_{PT}, C_D, L	I_D

TABLE 1 – Effect of Physical Changes on Diode Characteristics

The effect of each change assumes all other properties remain constant. The cathode region is considered to be heavily doped, therefore the anode resistivity determines the junction characteristics; the general behavior is the same if the anode region is heavily doped and the cathode region lightly doped.

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OF SEMICONDUCTORS

Three basic processes play a part in the removal of heat from the rectifier junction to the ambient air: (1) Conduction (heat traveling through a material), (2) Convection (heat traveling by transferring energy from one molecule to another) and, (3) Radiation (heat being emitted). Heat flows by conduction from the die to the package in a stud or base-mounted part, but it flows from the die through the leads to the mounting terminals in a lead-mounted part. For case-mounted parts, convection and radiation are of primary importance in the design of the heat exchanger, which is covered in Chapter 10. For lead-mounted parts, radiation and convection from the body may both be quite important. Both will be discussed later in this chapter. Transient thermal considerations and thermal runaway are also important design factors and are discussed near the end of this chapter.

In order to simplify the analysis of heat flow, the concept of thermal resistance is used. Just as a material offers resistance to the flow of current, it may be thought of as offering resistance to the flow of heat. Resistance to heat flow is called thermal resistance and for steady state conditions is given as:

$$R_\theta = \Delta T/P \tag{1a}$$

or

$$\Delta T = R_\theta P \tag{1b}$$

where: R_θ = the thermal resistance in °C/W,

ΔT = the temperature difference between points in °C,

P = the power in watts.

THERMAL MODELS

Thermal resistance may be used to form electrical models which permit calculation of the temperature rise in a system. Similar to an electrical physical resistance, thermal resistance is not constant; changes in mounting, temperature, or power levels will cause some modification of values. Nevertheless, the concept is a very valuable tool in handling thermal problems.

By use of a thermal model, complex thermal systems may be easily analyzed using electrical network theorems. The following sections discuss models for single chip case- and lead-mounted parts and for multiple chip assemblies.

Thermal Models for Case-Mounted Rectifiers

The total thermal resistance, junction-to-case, is composed of several smaller thermal resistances, as shown in Figure 1. The die-bond thermal resistance is generally the largest value. Note that the various values are determined by the design of the device: the size of the chip, the type of the die bond, and the type and material of the package. Variations among parts

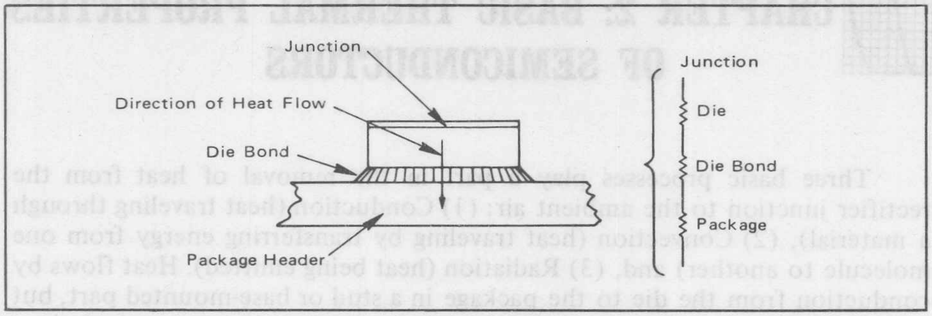


Figure 1 — Thermal Resistance Components of the Junction-to-Case Thermal Resistance.

from a given product line are the result of variations in the die-bond thermal resistance. It is affected by the type of solder used; furthermore, some parts may have insulators or a piece of material inserted between the die and the package to take up stresses developed by differing thermal coefficients of expansion of the package and of the die. As a general guide, however, thermal resistance, as a function of the die area for various common diode packages, behaves as shown in Figure 2.

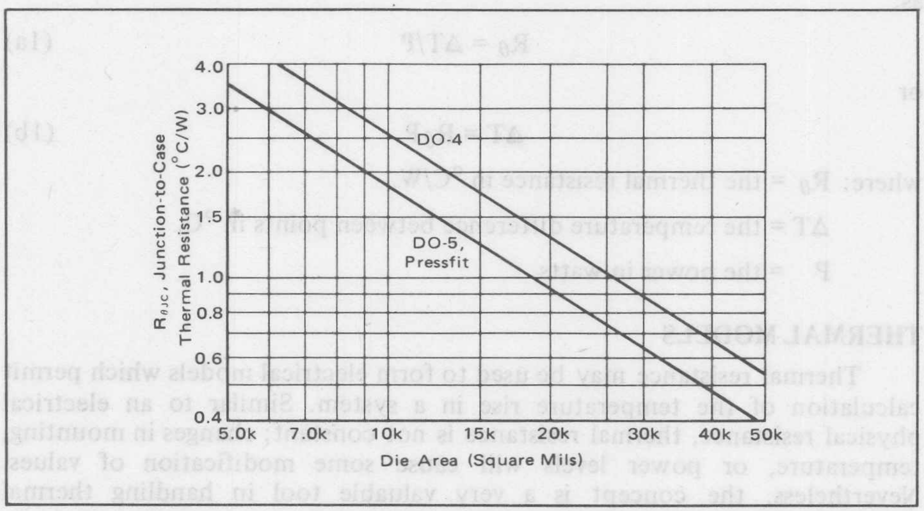


Figure 2 — Typical Thermal Resistance of Common Rectifier Packages Having Copper Material in the Heat Flow Path (Data Averaged From Measurements at Motorola).

Thermal resistance follows the same general equation as does electrical resistance, i.e.,

$$R_\theta = \frac{\rho\, l}{A} \tag{2}$$

where: ρ = thermal resistivity,

l = length of thermal path,

A = area of thermal path.

The equation states that thermal resistance is inversely proportional to area; however, the data of Figure 2 does not indicate this relationship exactly. The deviation is caused because the area of heat flow through the package is not the same as the die area. As heat flows, it spreads out toward the edges of the package; consequently, as larger die are placed in a given package, the area for spreading reduces proportionally.

Thermal Models for Lead-Mounted Parts

In the axial lead-mounted rectifier, heat travels down both leads to some kind of a heat dissipator, which is often nothing more than a printed circuit wiring pattern. Heat is also carried from the package and from the leads by convection and radiation, which make the thermal circuit model immensely more complicated for a lead-mounted part than for a case- or stud-mounted part. However certain lead-mounted parts are easily handled because the thermal resistance of the leads is identical and quite low compared to the package radiation and convection components which may be neglected. Examples of parts in which this simplified approach is satisfactory are the MR751 series. Thermal resistance as a function of lead length, is shown in Figure 3. Note that the thermal resistance is linearly proportional to lead length indicating that the package plays a negligible role in the total thermal resistance. If the package were not negligible, the lines would curve as the lead length increased.

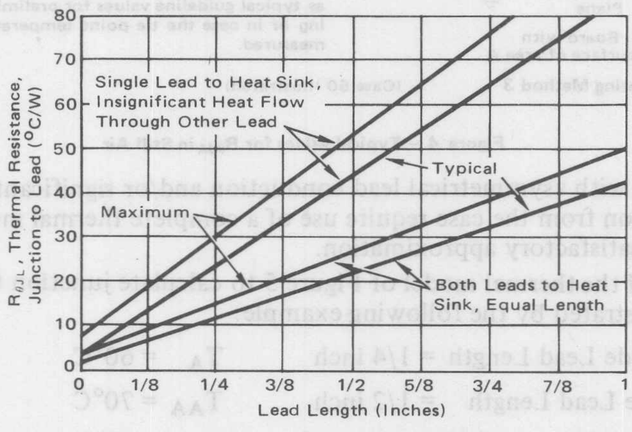
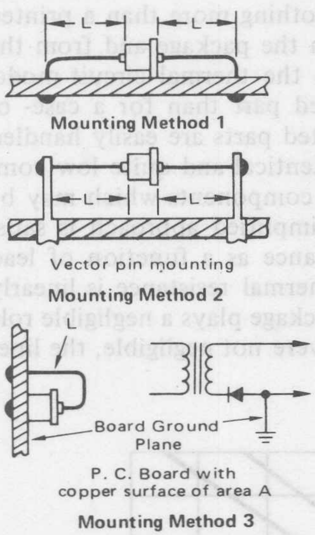


Figure 3 – Thermal Resistance as a Function of Lead Length for MR751 Series Axial-Lead Recifiers.

Data is often given for the case where both leads have identical lengths. However, identical lead lengths will not result in lowest thermal resistance to the mounting points since the net thermal resistance is composed of two parallel paths. The lowest net value will always occur when one of the paths is made as low as possible. For example, suppose a mounting situation is encountered where the leads must take up a 1-inch span. If each lead were 1/2-inch long, the thermal resistance (from Figure 3) is 13°C/W maximum. However, the device could be mounted with one lead 1/8-inch long and the other 7/8-inch long. The thermal resistance from junction to each lead is 4°C/W for the 1/8-inch lead and 23°C/W for the 7/8-inch lead.

The net thermal resistance is the parallel combination 3.4°C/W. The reduction from 13°C/W is quite significant but to take advantage of this reduction the mounting terminal must have a low thermal resistance. Also, as the span becomes less, the advantages of asymmetrical mounting become less significant.

As a design guide, when using lead-mounted parts, Figure 4 shows typical data for three popular case types. As can be better appreciated after studying the problems in Chapter 10, junction to ambient thermal resistance cannot be regarded as a design constant.



CASE #	MOUNTING METHOD	LEAD LENGTH L 1/8"	1/4"	1/2"	3/4"
59 (DO-41)	1	65	72	82	92
	2	74	81	91	101
	3	40°C/W (L = 3/8", A = 2.22"^{2})			
60	1	–	55		58
	2	–	65	–	68
	3	25°C/W (L = 5/8", A = 6.25"^{2})			
267	1	50	51	53	55
	2	58	59	61	63
	3	28°C/W (L = 1/2", A = 6.25"^{2})			

Data shown for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

(Case 60 Illustrated)

Figure 4 — Typical values for $R_{\theta JA}$ in Still Air

Parts with asymmetrical lead conduction and/or significant convection and radiation from the case require use of a complete thermal model. Figure 5 shows a satisfactory approximation.

Use of the thermal model of Figure 5 to calculate junction temperature will be illustrated by the following example:

Cathode Lead Length = 1/4 inch $\qquad T_A = 60°C$

Anode Lead Length = 1/2 inch $\qquad T_{AA} = 70°C$

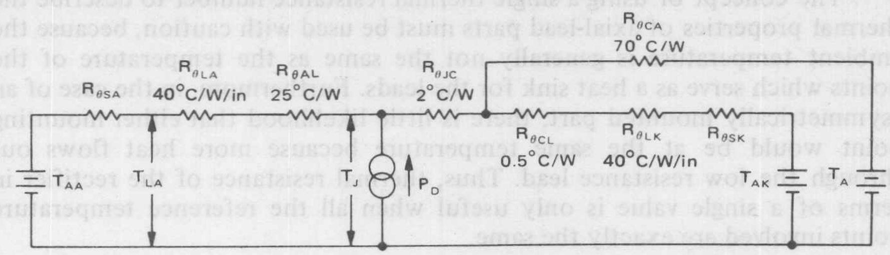
$R_{\theta SA} = R_{\theta SK} = 40°C/W$ (typical for printed board wiring). $\qquad T_{AK} = 80°C$

From the data in the figure, calculate:

$R_{\theta LA} = 40 \times 1/2 = 20°C/W$,

$R_{\theta LK} = 40 \times 1/4 = 10°C/W$.

The model of Figure 5 may be successively simplified as illustrated by Figure 6. The resulting junction temperature is 117°C. Thus the effective thermal resistance, junction-to-ambient, is (117-60)/2 = 28.5°C/W; however, the number is not especially meaningful because the temperatures of the ambient and the printed board wiring are not the same.

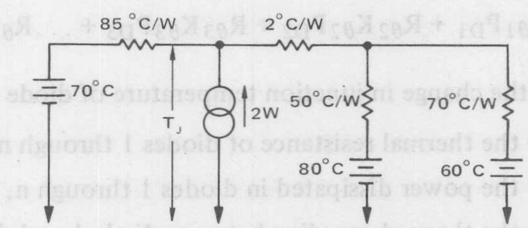


Use of the above model permits calculation of average junction temperature for any mounting situation. Lowest values of thermal resistance will occur when the cathode lead is brought as close as possible to a heat dissipator; as heat conduction through the anode lead is small. Terms in the model are defined as follows:

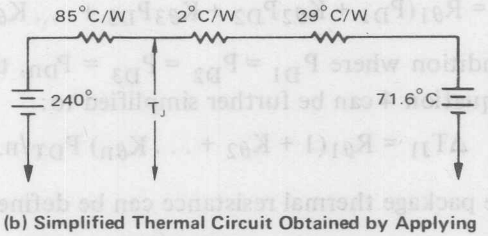
TEMPERATURES	THERMAL RESISTANCES
T_A Ambient	$R_{\theta CA}$ = Case to Ambient
T_{AA} = Anode Heat Sink Ambient	$R_{\theta SA}$ = Anode Lead Heat Sink to Ambient
T_{AK} = Cathode Heat Sink Ambient	$R_{\theta SK}$ = Cathode Lead Heat Sink to Ambient
T_{LA} = Anode Lead	$R_{\theta LA}$ = Anode Lead
T_{LK} = Cathode Lead	$R_{\theta LK}$ = Cathode Lead
T_J = Junction	$R_{\theta CL}$ = Case to Cathode Lead
	$R_{\theta JC}$ = Junction to Case*
	$R_{\theta AL}$ = Junction to Anode Lead (S bend)

*Case temperature reference is at cathode end.

Figure 5 — Approximate Thermal Circuit Model for a Case 60 Part



(a) Model with Example Numbers Inserted



(b) Simplified Thermal Circuit Obtained by Applying Thevenins Theorum to Each Side of the Model

Figure 6 — Successive Steps in the Solution of the Example in the Text. Thermal Problems May be Solved by Application of Network Theorems.

The concept of using a single thermal resistance number to describe the thermal properties of axial-lead parts must be used with caution, because the ambient temperature is generally not the same as the temperature of the points which serve as a heat sink for the leads. Furthermore, in the case of an asymmetrically mounted part, there is little likelihood that either mounting point would be at the same temperature because more heat flows out through the low resistance lead. Thus, thermal resistance of the rectifier in terms of a single value is only useful when all the reference temperature points involved are exactly the same.

Thermal Models for Multiple Chip Devices

Rectifiers having more than one die per package, e.g., full-wave, bridge, or three-phase assemblies, have a considerably more complicated thermal situation because of thermal coupling between the die. To appreciate how the coupling problem can be handled, consider the thermal model which applies to an MDA2500, as shown in Figure 7. Coupling is represented by resistances connecting all the die together. The coupling between adjacent die is primarily a result of heat transfer through the lead frame, but the epoxy encapsulant is also a thermal conductor. In addition, each die is also coupled to the opposite one through the lead frame as well as through the epoxy molding in the center of the assembly. The epoxy coupling requires the addition of two other resistance paths.

Since the model is so complex, it is easier to work in terms of a coupling factor. The general equation for thermally coupled die can be written as follows:

$$\Delta T_{J1} = R_{\theta 1}P_{D1} + R_{\theta 2}K_{\theta 2}P_{D2} + R_{\theta 3}K_{\theta 3}P_{D3} + \ldots R_{\theta n}K_{\theta n}P_{Dn} \quad (3)$$

where: ΔT_{J1} is the change in junction temperature of diode 1,

$R_{\theta 1} - n$ = the thermal resistance of diodes 1 through n,

$P_{D1} - n$ = the power dissipated in diodes 1 through n,

$K_{\theta 2} - n$ = the thermal coupling between diode 1 and diodes 2 through 4.

Assuming equal thermal resistance for each die, Equation 3 simplifies to

$$\Delta T_{J1} = R_{\theta 1}(P_{D1} + K_{\theta 2}P_{D2} + K_{\theta 3}P_{D3} + \ldots K_{\theta n}P_{Dn}). \quad (4)$$

For the condition where $P_{D1} = P_{D2} = P_{D3} = P_{Dn}$, the total dissipation $P_{DT} = n\,P_{D1}$. Equation 4 can be further simplified to:

$$\Delta T_{J1} = R_{\theta 1}(1 + K_{\theta 2} + \ldots K_{\theta n})\,P_{DT}/n. \quad (5)$$

An effective package thermal resistance can be defined as follows:

$$R_{\theta(Eff)} = \Delta T_{J1}/P_{DT} \quad (6)$$

Combining Equations (5) and (6) yields:

$$R_{\theta(Eff)} = R_{\theta 1}\,(1 + K_{\theta 2} + K_{\theta 3} + \ldots K_{\theta n})/n \quad (7)$$

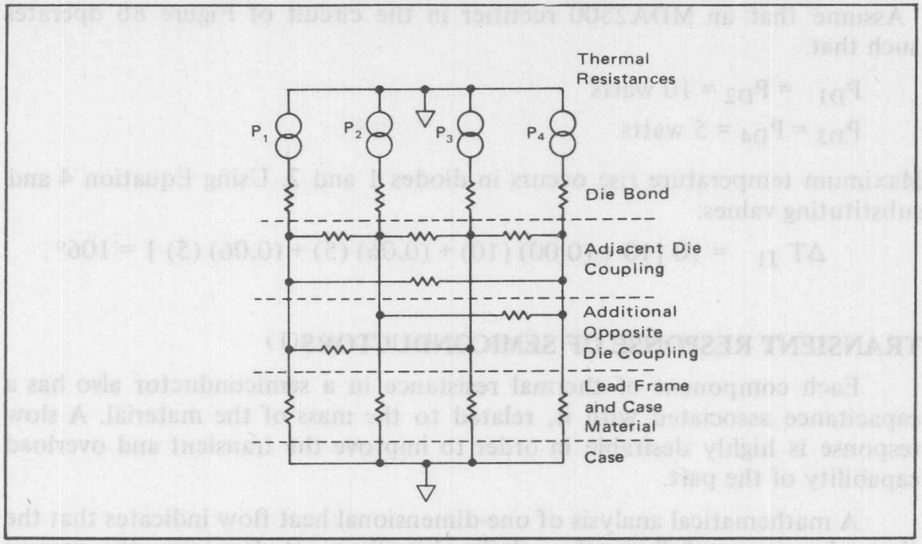


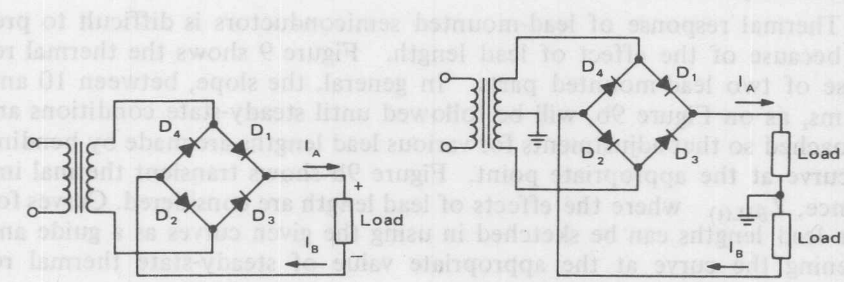
Figure 7 – Thermal Model for an MDA2500 Bridge Assembly.

For the MDA2500 rectifier assembly, thermal coupling between opposite diodes is negligible, and between adjacent diodes, 6%. Using the thermal resistance limit of the MDA2500 of 10° C/W and its coupling factors in Equation 7 find

$$R_{\theta(\text{Eff})} = 10(1 + 0.06 + 0.00 + 0.06)\,/4 = 2.8°\,\text{C/W}.$$

This value is the one specified on the data sheet as the effective bridge thermal resistance, junction-to-case. Satisfactory average, steady-state temperature calculations may be made by multiplying $R_{\theta(\text{Eff})}$ by the total power dissipated in the package under a given load condition.

The coupling factor is particularly valuable when a bridge assembly is operated in the split load circuit of Figure 8b instead of the more usual bridge circuit of Figure 8a. The following example illustrates the use of the data.



(a) Standard Circuit

(b) Split Load Circuit

Figure 8 – Basic Circuit Uses For Bridge Rectifiers. See Chapter 4 for Description of Circuit Operation

Assume that an MDA2500 rectifier in the circuit of Figure 8b operates such that

$$P_{D1} = P_{D2} = 10 \text{ watts}$$

$$P_{D3} = P_{D4} = 5 \text{ watts.}$$

Maximum temperature rise occurs in diodes 1 and 2. Using Equation 4 and substituting values:

$$\Delta T_{J1} = 10\,[10 + (0.00)(10) + (0.06)(5) + (0.06)(5)] = 106°.$$

TRANSIENT RESPONSE OF SEMICONDUCTORS(1)

Each component of thermal resistance in a semiconductor also has a capacitance associated with it, related to the mass of the material. A slow response is highly desirable in order to improve the transient and overload capability of the part.

A mathematical analysis of one-dimensional heat flow indicates that the thermal response follows the relationship $T_J \propto \sqrt{t}$. However, the various time constants associated with a semiconductor affixed to a package, and the fact that heat flow is not usually one-dimensional, make the response extremely difficult to calculate. The most practical method of handling the transient thermal problem is to measure the thermal response of the semiconductor to a step of input power and to present the data in a graph. The thermal resistance as a function of time may be calculated by the equation below:

$$Z_{\theta JR(t)} = r(t)\, R_{\theta JR} \tag{8}$$

where: $r(t)$ = fraction of steady value at a given time,

$R_{\theta JR}$ = thermal resistance, junction to a reference point.

Choice of reference point depends on the type of part. For case-mounted parts, the logical reference is the case. For lead-mounted parts the leads are generally chosen; however, the ambient is sometimes used. In the following sections the transient response of case-mounted and lead-mounted parts will be examined.

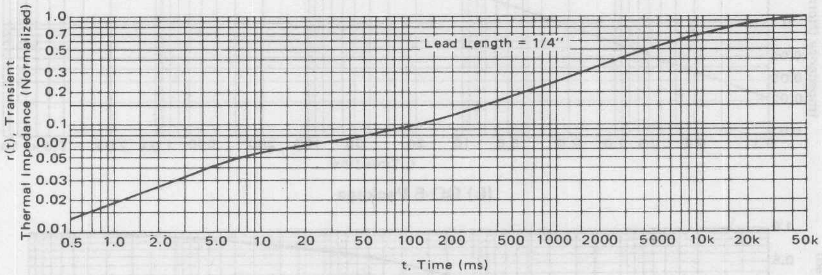
Thermal Response Data

Thermal response of lead-mounted semiconductors is difficult to present because of the effect of lead length. Figure 9 shows the thermal response of two lead-mounted parts. In general, the slope, between 10 and 100 ms, as on Figure 9b, will be followed until steady-state conditions are approached so that adjustments for various lead lengths are made by bending the curve at the appropriate point. Figure 9b shows transient thermal impedance, $Z_{\theta JL(t)}$ where the effects of lead length are considered. Curves for other lead lengths can be sketched in using the given curves as a guide and flattening the curve at the appropriate value of steady-state thermal resistance.

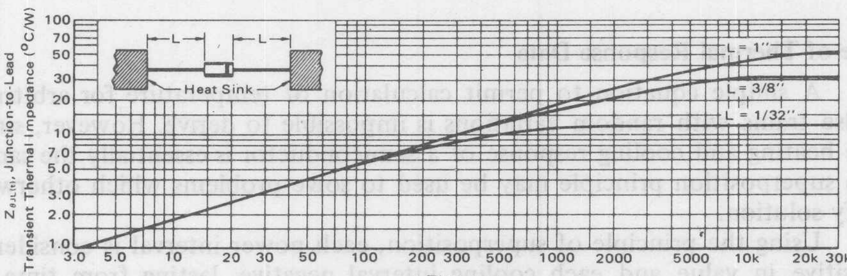
Figure 10 shows response curves for typical power rectifiers in the DO-4, DO-5 and DO-21 (press fit) case. Differences in dies and manufacturing techniques make it difficult to explain behavior, although it is evident that the more massive packages and larger die do have slower responses.

Measurements of various rectifier assemblies have revealed that times well over 10 seconds are required for temperature changes of one die to become manifest at one of the other die in an assembly. As a result, transient coupling can be neglected because of the relatively high frequencies employed in electronic work.

When rectifiers are used in intermittant operation the thermal response of the heat sink may be used to advantage. Heat sink properties are discussed in chapter 10.



(a) Case 59 (surmetic) with fast recovery diode, plotted normalized.



(b) Case 59 (surmetic) with standard diode, plotted in terms of °C/W

Figure 9 – Typical Thermal Response of Lead-Mounted Rectifiers.

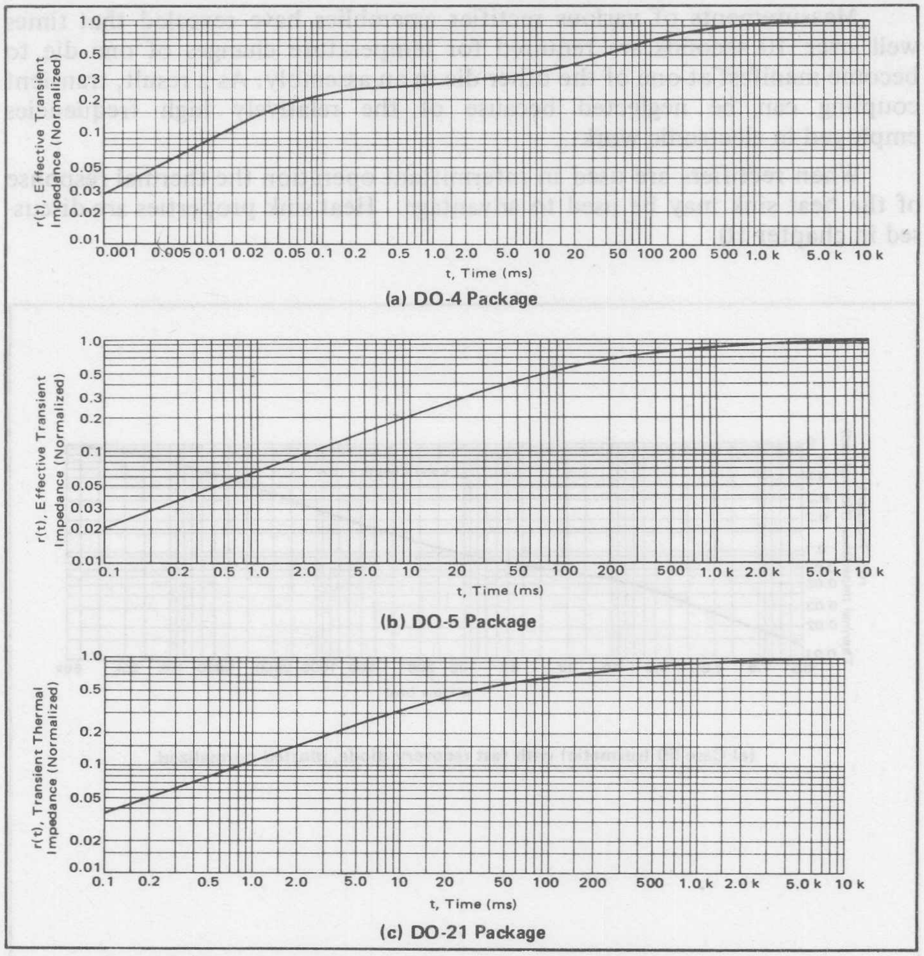


Figure 10 – Typical Thermal Respone of Stud-Mounted and Press-fit Rectifiers.

Use of Thermal Response Data

A simple equation to permit calculation of temperature for arbitrary pulse trains with random variations is impossible to derive. However, since the heating and cooling response of a semiconductor is essentially the same, the superposition principle may be used to solve problems which otherwise defy solution.

Using the principle of superposition, each power interval is considered positive in value and each cooling interval negative, lasting from time of application to infinity. By multiplying the thermal resistance at a particular time by the magnitude of the power pulse applied, the magnitude of the junction temperature change at a particular time is obtained. The net junction temperature is the algebraic sum of the terms.

The application of the superposition principle is easily seen by studying Figure 11. Part a illustrates the applied power pulses. Part b shows these pulses transformed into pulses lasting from time of application and extending to infinity; at t_o, P_1 starts and extends to infinity; at t_1, a pulse $(-P_1)$ is considered to be present and thereby cancels P_1 from time t_1, and so

forth with the other pulses. The junction temperature changes, due to these imagined positive and negative pulses, are shown in part c. The actual junction temperature is the algebraic sum as shown in part d.

Problems may be solved by applying the superposition principle exactly as described; the technique is referred to as the pulse-by-pulse method. It yields satisfactory results when the total time of interest is much less than the time required to achieve steady state conditions. This method must be used when an uncertainty exists in a random pulse train as to which pulse will cause the highest temperature.

Where surges occur with uniform trains of repetitive pulses, more accurate answers with less work are obtained by averaging the power pulses to achieve an average power pulse; the temperature is calculated at the end of the surge or overload following the average power pulse. The basis of this method is shown in Figure 12.

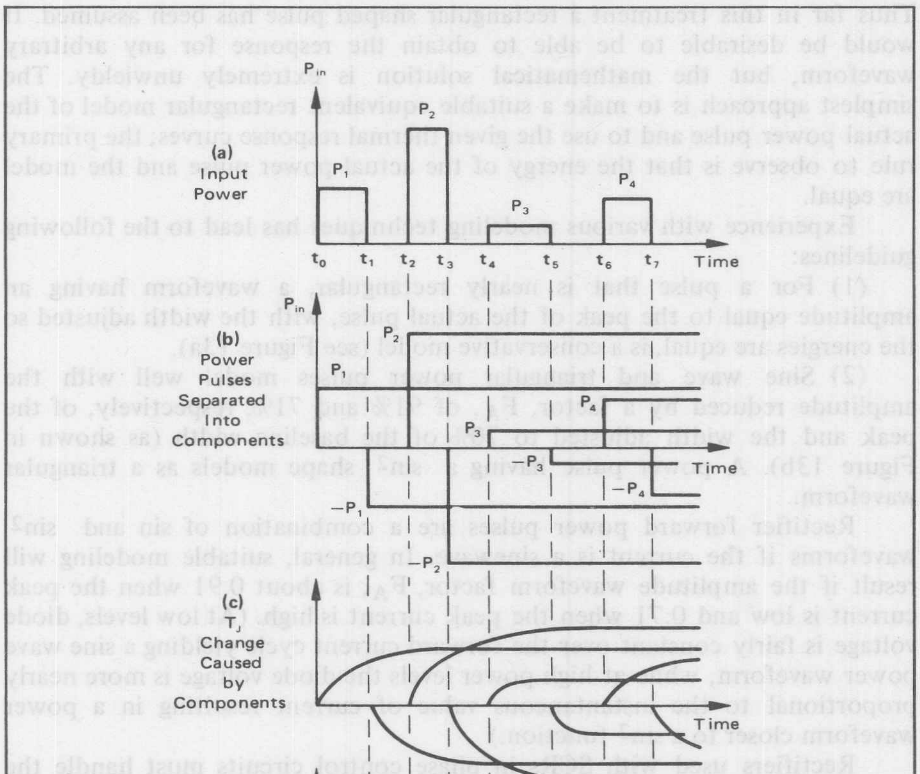


Figure 11 — Application of Superposition Principle

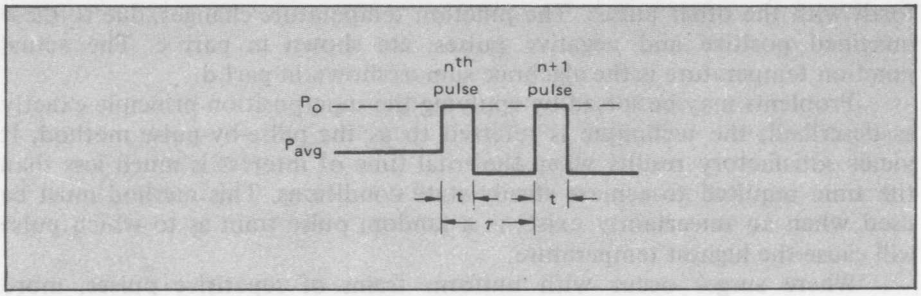


Figure 12 – Model For a Repetitive Equal Pulse Train

Handling Non-Rectangular Pulses

The thermal response curves, Figures 9 and 10 are based on a step change of power; the response will not be the same for other waveforms. Thus far in this treatment a rectangular shaped pulse has been assumed. It would be desirable to be able to obtain the response for any arbitrary waveform, but the mathematical solution is extremely unwieldy. The simplest approach is to make a suitable equivalent rectangular model of the actual power pulse and to use the given thermal response curves; the primary rule to observe is that the energy of the actual power pulse and the model are equal.

Experience with various modeling techniques has lead to the following guidelines:

(1) For a pulse that is nearly rectangular, a waveform having an amplitude equal to the peak of the actual pulse, with the width adjusted so the energies are equal, is a conservative model (see Figure 13a).

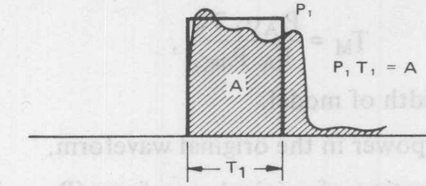
(2) Sine wave and triangular power pulses model well with the amplitude reduced by a factor, F_A, of 91% and 71%, respectively, of the peak and the width adjusted to 70% of the baseline width (as shown in Figure 13b). A power pulse having a $\sin^2$ shape models as a triangular waveform.

Rectifier forward power pulses are a combination of sin and $\sin^2$ waveforms if the current is a sinewave. In general, suitable modeling will result if the amplitude waveform factor, F_A, is about 0.91 when the peak current is low and 0.71 when the peak current is high. (At low levels, diode voltage is fairly constant over the forward current cycle yielding a sine wave power waveform, while at high power levels the diode voltage is more nearly proportional to the instantaneous value of current resulting in a power waveform closer to a $\sin^2$ function.)

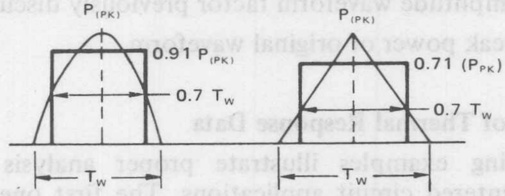
Rectifiers used with SCRs in phase control circuits must handle the current waveforms of part c. Empirically developed modeling rules for SCR power losses are indicated; they are slightly more conservative when used with rectifiers than with SCRs.

Power pulses having more complex waveforms could be modeled by using two or more pulses as shown in Figure 13d.

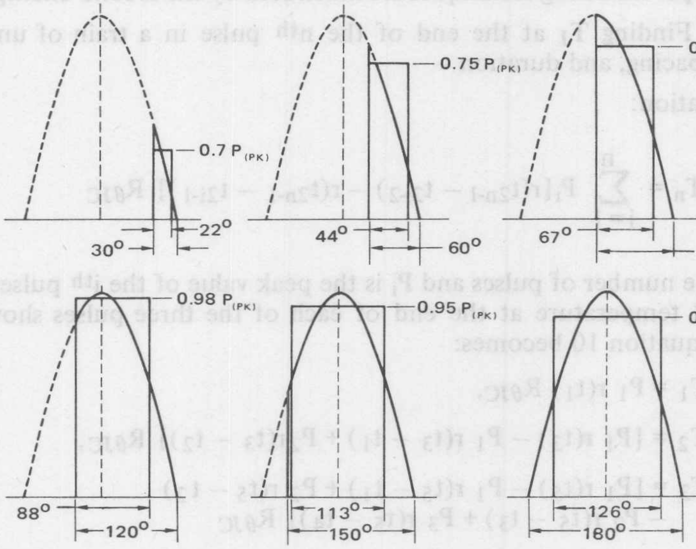
A point to remember is that a high amplitude pulse of a given amount of energy will produce a higher rise in junction temperature than will a lower amplitude pulse of longer duration having the same energy.



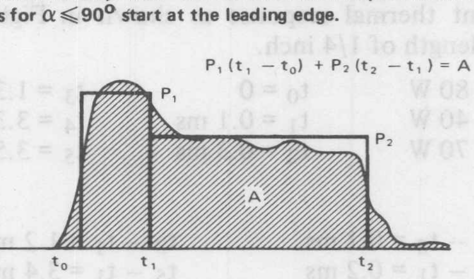
(a) Model for a nearly Rectangular Waveform



(b) Models for Sine Wave and Triangular Pulses



(c) Models of SCR Current Waveforms for various conduction angles (α). Pulses for $\alpha \geqslant 120^o$ are centered with respect to the sine wave. Pulses for $\alpha \leqslant 90^o$ start at the leading edge.



(d) Model for a Complex Waveform

Figure 13 — Models for Frequently Encountered Power Pulses.

The general equation for modeling is:

$$T_M = \frac{P_{(AV)}\,T_W}{F_A\,P_{(PK)}}, \tag{9}$$

where: T_M = pulse width of model,

P_{AV} = average power in the original waveform,

T_W = time duration of original waveform ($P_{(AV)}\,T_W$ = Area under the power waveform,

F_A = amplitude waveform factor previously discussed,

$P_{(PK)}$ = peak power of original waveform.

Examples of Use of Thermal Response Data

The following examples illustrate proper analysis procedures for commonly encountered circuit applications. The first one is for a random pulse train, and the second is for a single-phase circuit subjected to an overload. Proper modeling techniques are illustrated by the second example.

Example 1: Finding T_J at the end of the n^{th} pulse in a train of unequal amplitude, spacing, and duration –

General Equation:

$$T_n = \sum_{i=1}^{n} P_i[r(t_{2n-1} - t_{2i-2}) - r(t_{2n-1} - t_{2i-1})]\;R_{\theta JC} \tag{10}$$

where n is the number of pulses and P_i is the peak value of the i^{th} pulse.

To find temperature at the end of each of the three pulses shown in Figure 14, Equation 10 becomes:

$$T_1 = P_1\,r(t_1)\,R_{\theta JC}, \tag{9a}$$

$$T_2 = [P_1\,r(t_3) - P_1\,r(t_3 - t_1) + P_2 r(t_3 - t_2)]\;R_{\theta JC}, \tag{9b}$$

$$T_3 = [P_1\,r(t_5) - P_1\,r(t_5 - t_1) + P_2\,r(t_5 - t_2) - P_2\,r(t_5 - t_3) + P_3\,r(t_5 - t_4)]\;R_{\theta JC} \tag{9c}$$

Assume the following pulse conditions are applied to a rectifier in Case 59 with a transient thermal response as shown in Figure 9a and $R_{\theta JL}$ = 31°C/W for a lead length of 1/4 inch.

$P_1 = 80$ W	$t_0 = 0$	$t_3 = 1.3$ ms
$P_2 = 40$ W	$t_1 = 0.1$ ms	$t_4 = 3.3$ ms
$P_3 = 70$ W	$t_2 = 0.3$ ms	$t_5 = 3.5$ ms

Therefore:

$t_1 - t_0 = 0.1$ ms	$t_3 - t_1 = 1.2$ ms
$t_2 - t_1 = 0.2$ ms	$t_5 - t_1 = 3.4$ ms
$t_3 - t_2 = 1$ ms	$t_5 - t_2 = 3.2$ ms
$t_4 - t_3 = 2$ ms	$t_5 - t_3 = 2.2$ ms
$t_5 - t_4 = 0.2$ ms	

Procedure:

Find $r(t_n - t_k)$ for preceding time intervals from Figure 10a; then substitute into Equation 9.

$$T_1 = P_1\, r(t_1)\, R_{\theta JL} = (80)(0.02)\, 31 \approx 50°C$$

$$\begin{aligned} T_2 &= [P_1\, r(t_3) - P_1\, r(t_3 - t_1) + P_2\, r(t_3 - t_2)]\, R_{\theta JL} \\ &= [80\,(0.058) - 80\,(0.056) + 40\,(0.054)]\, 31 \\ &= [4.64 - 4.48 + 2.16]\, 31 = (2.32)\, 31 = 72°C \end{aligned}$$

$$\begin{aligned} T_3\ &[P_1\, r(t_5) - P_1\, r(t_5 - t_1) + P_2\, r(t_5 - t_2) \\ &- P_2\, r(t_5 - t_3) + P_3\, r(t_5 - t_4)]\, R_{\theta JL} \\ &= [80\,(0.074) - 80\,(0.073) + 40\,(0.072) - 40\,(0.066) + 60\,(0.027)]\, 31 \\ &= [(5.91 - 5.83) + (2.88 - 2.64) + (1.62)]\, 31^{\dagger} \\ &= (1.84)\, 31 \approx 57°C \end{aligned}$$

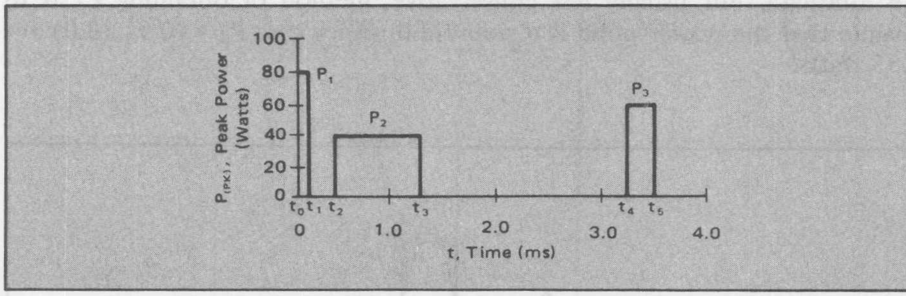


Figure 14 – Pulse Train Analyzed For Peak Temperatures in Example 1 in Text

Note, by inspecting the last bracketed term in the equation above it is apparent that very little residual temperature is left from the first pulse at the end of the second and third pulse.† Also note that the second pulse gave the highest value of junction temperature, a fact not so obvious from inspection of the figure. However, considerable residual temperature from the second pulse was present at the end of the third pulse.

Example 2: Find T_J at the end of an overload condition in a train of pulse of equal amplitude, spacing, and duration.

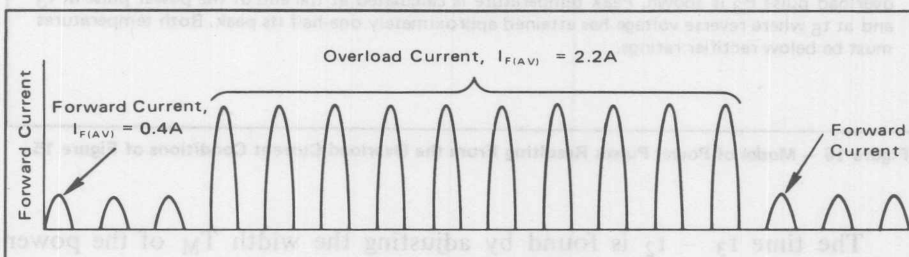


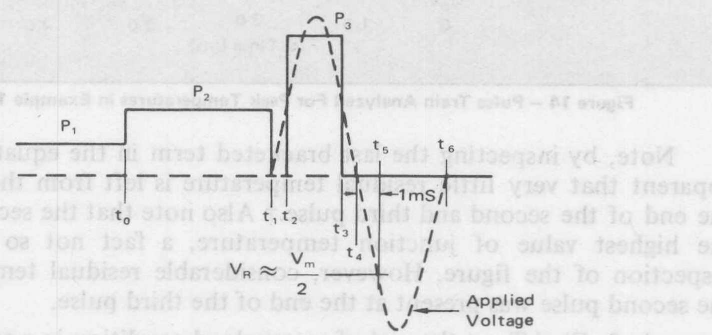
Figure 15 – Overload Current Condition Used in Example 2 to Calculate Peak Junction Temperature As Waveforms Show, the Load is Resistive.

†Relative amounts of residual temperature from P_1, P_2 and P_3 respectively are indicated by the terms in parenthesis.

The overload-current condition shown in Figure 15 is applied to the rectifier used in the previous example and is modeled as shown in Figure 16. P_1 is the average power dissipation before the overload condition, P_2 is the average power dissipation during the overload condition, and P_3 is an equivalent peak power pulse resulting from the last overload pulse in the overload train. For the average current of 0.4 amperes, before the overload condition, and the average current of 2.2 amperes during the overload, the average power dissipation can be determined from rectifier power dissipation data. Obtain P_1 = 0.4 watts and P_2 = 3.0 watts for a resistive load. P_3 is a peak power and is obtained by noting that an average current of 2.2 A has a peak value of 6.9 amperes (3.14 x 2.2) causing a peak voltage of 1.45 volts, a value obtainable from rectifier $V_F - I_F$ data. Using the modeling rules, the equivalent rectangular pulse, P_3, using a conservative waveform factor of 0.91 yields

$$P_3 = (0.91)(6.9)(1.45) = 9.1 \text{ watts.}$$

An alternate, but usually less conservative, method of obtaining P_3 is to assume that the power pulse is a sinusoid in which case $P_3 = (0.91)(3.0)\,\pi = 8.55$ watts.



P_1 is average power prior to overload, P_2 is average overload power; from t_1 to t_2 an equivalent overload pulse P_3 is shown. Peak temperature is calculated at the end of the power pulse at t_3 and at t_5 where reverse voltage has attained approximately one-half its peak. Both temperatures must be below rectifier ratings.

Figure 16 – Model of Power Pulses Resulting From the Overload Current Conditions of Figure 15.

The time $t_3 - t_2$ is found by adjusting the width T_M of the power pulse P_3 for equivalent energy by using Equation 9 to obtain

$$t_3 - t_2 = T_M = \frac{P_2\, T_W}{P_3}$$

$$(t_3 - t_2) = \frac{(3)\,(16.667)}{9.1} = 5.5 \text{ ms;}$$

thus,

$$(t_2 - t_1) = (t_4 - t_3) = \frac{8.34 - 5.5}{2} = \frac{2.84}{2} = 1.42 \text{ ms}$$

$t_1 = (9)(16.67) = 150$ ms $\quad t_3 - t_1 = 6.92$

$t_2 = t_1 + (t_2 - t_1) = 151.42 \quad t_5 - t_1 = 9.34$

$t_3 = t_2 + (t_3 - t_2) = 156.92 \quad t_5 - t_2 = 7.92$

$t_5 = t_3 + (t_4 - t_3) + 1 = 159.34 \quad t_5 - t_3 = 2.42$

The general equations used to calculate the junction temperature rise above ambient at t_3 and t_5 are as follows:

$$T_3 = [P_1 - P_1 r(t_3) + P_2 r(t_3) - P_2 r(t_3 - t_1) + P_3 r(t_3 - t_2)]\ R_{\theta JL}, \tag{11a}$$

$$T_5 = [P_1 - P_1 r(t_5) + P_2 r(t_5 - P_2 r(t_5 - t_1) + P_3 r(t_5 - t_2) - P_3 r(t_5 - t_3]\ R_{\theta JL}. \tag{11b}$$

Solving

$$T_3 = [0.4 - 0.4(0.315) + 3(0.315) - 3(0.088) + 9.1(0.083)]\ 31$$
$$= 1.71(31) \approx 53°\text{C},$$

$$T_5 = [0.4 - 0.4(0.317) + 3(0.317) - 3(0.096) + 9.1(0.091) - 9.1(0.068)]$$
$$= 1.15(31) \approx 36°\text{C}.$$

Thus the junction temperature has cooled 17°C from the time t_3 to time t_5. Reverse power dissipation, due to reverse voltage and leakage current, has been assumed negligible in the above example. If this is not the case, average reverse power dissipation is added to pulses P_1 and P_2; also a peak reverse power pulse is added between t_4 and t_5. Equations 11a and 11b are accordingly modified.

THERMAL RUNAWAY

Rectifier circuits may operate the rectifying diode such that thermal runaway is liable to occur and to result in destruction of the diode. The problem arises because reverse current is such a strong function of temperature and – to a lesser degree – voltage. As power is applied, junction temperature increases causing reverse power losses to increase when the diode is blocking. The reverse power loss adds to the forward power and causes a further increase in temperature. Thus a regenerative process is operating.

In any thermal system, the conditions for thermal stability are such that the system must be capable of dissipating more heat than is generated, i.e., the heat generated in the semiconductor must be less than the thermal conductivity from junction-to-air. Mathematically, the conditions for stability are

$$dP_D/dT_J < 1/R_{\theta JA} \tag{12}$$

where dP_D/dT_J = change in power dissipation per unit change in temperature,

$R_{\theta JA}$ = thermal resistance, junction-to-ambient.

A graphical approach[2] may be used to analyze the problem and illustrate the principles involved. It also permits the influence of ambient temperature and thermal resistance to be readily seen. Figure 17 shows how this is done; values are typical of those encounted with Schottky barrier power rectifiers.

Curve A is a plot of the heat generated at the rectifier junction versus junction temperature. The ordinate is simply $P_{R(AV)}$ and may be found from I_R vs. T_J and V_R curves; it is easy to do for dc conditions. The slope of curve A is dP_D/dT_J.

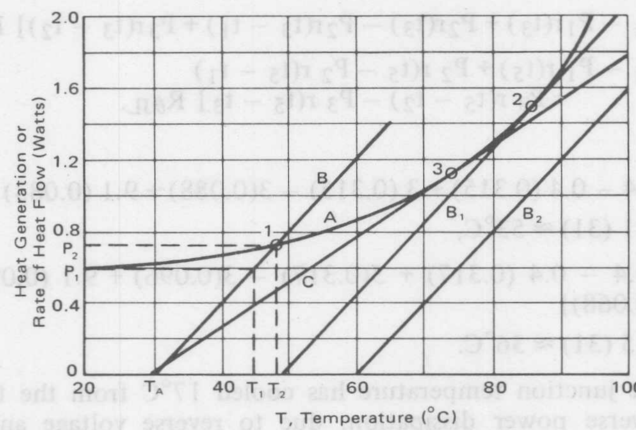


Figure 17 – Graphical Analysis of Thermal Runaway

Curve B represents the power-dissipation capability (rate of heat flow) of the equivalent thermal circuit as a function of the junction temperature of the rectifier. The slope can be seen to be $1/R_{\theta JA}$, which corresponds to the thermal conductivity of the total thermal circuit from junction to ambient air.

With no voltage applied, the unit dissipates no power and, thus, the junction temperature is the same as the ambient. In Figure 17, this condition corresponds to the point T_A. When voltages are applied to the circuit, the heat generated by the semiconductor (in the form of dissipation) is P_1. This amount of internal heat generation in the semiconductor requires that the junction temperature increase to T_1. However, since the junction temperature has now been increased, the total power generated by the semiconductor must increase to P_2. In this manner, the junction temperature and resultant power generation increase until a stable condition is reached at point 1, where the power-generation and thermal-conductance curves intersect, resulting in junction temperature, T_2. T_2 is approximately 58°C; the ambient temperature is at the intersection of curve B with the abscissa, 30°C for this example.

It is now possible to predict the effect of changing the ambient temperature. If the ambient temperature were increased, curve B would be translated to the right, resulting in a higher junction temperature because the

intersection of curve A would be to the right of point 1. If the ambient temperature increased to 49°C (curve B_1), the junction temperature would be about 85°C. At values of ambient temperature below 49°C, for this particular thermal resistance (25°C/W), the circuit always fulfills the thermal stability criterion, i.e., $dP_D/dT_J < R_{\theta JA}$ and is therefore a thermally stable circuit. At an ambient temperature 49°C, curve B_1 is tangent to curve A at point 2, where $dP_D/dT_J = 1/R_{\theta JA}$. Under these conditions the circuit is conditionally stable, since a small incremental increase in junction temperature will cause an unstable condition. A further rise in the ambient temperature will cause the thermal conductance curve B_1 to fall below the power generation curve as shown by B_2. Under these conditions, the semiconductor junction temperature cannot stabilize. The power generated within the semiconductor continues to increase in search of a stable condition until the junction is destroyed.

From this representation, the effect of changing the thermal conductance can be determined. If the cooling facility is changed (for instance, a better heat sink is used), the junction will run cooler for a given ambient temperature, since the slope, curve B, will be increased. Curve C shows what happens if $R_{\theta JA}$ is increased to 40°C/W. Note that the maximum ambient temperature allowed is 29°C and that the junction temperature is at 75°C at the point of thermal runaway, (point 3).

To aid the circuit designer in applying rectifiers having reverse leakage high enough to require that thermal runaway be considered in the design, a simplified approach has been devised and is presented on applicable Motorola data sheets. It is based on the relationship

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}\, P_{F(AV)} - R_{\theta JA}\, P_{R(AV)}. \qquad (13)$$

where $T_{A(max)}$ = maximum allowable ambient temperature,

$T_{J(max)}$ = maximum allowable junction temperature (rated limit or the temperature at which thermal runaway occurs, whichever is lowest),

$P_{F(AV)}$ = average forward power dissipation,

$P_{R(AV)}$ = average reverse power dissipation,

$R_{\theta JA}$ = junction-to-ambient thermal resistance.

A reference temperature is defined by Equation 14:

$$T_R = T_{J(max)} - R_{\theta JA}\, P_{R(AV)}. \qquad (14)$$

The reference temperature T_R may be limited only by $P_{R(AV)}$ or may be limited by thermal runaway. T_R is obtained by a computer solution of the basic stability criteria boundary given in Equation 12 and explained in the preceding discussion. T_R data is presented on graphs similar to that of Figure 18. With T_R known, $T_{A(max)}$ is found from

$$T_{A(max)} = T_R - R_{\theta JA}\, P_{F(AV)} \qquad (15)$$

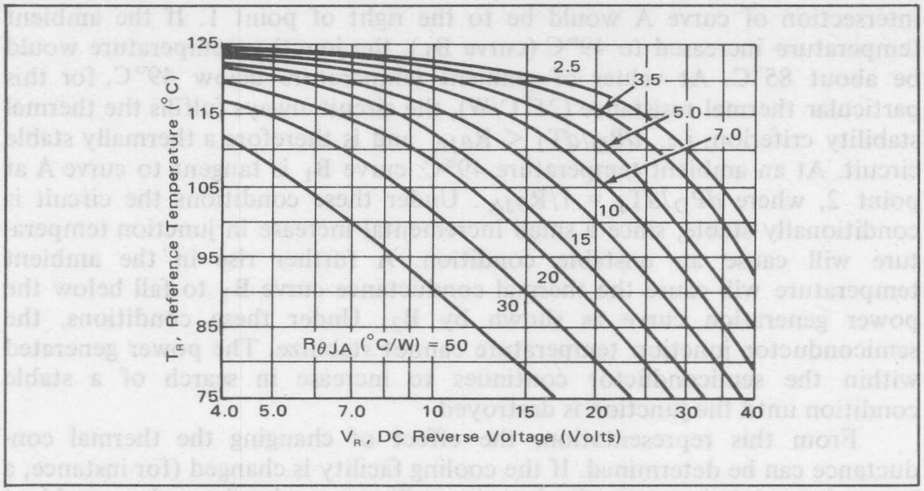


Figure 18 — Maximum Reference Temperature For a Shottky Rectifier

Figure 18 shows how T_R is limited by both $T_{J(max)}$ and thermal runaway. The transition between these two limitations is evident on the curves of Figure 18 as a difference in the rate of change of the slope in the vicinity of 115°C. The data is based upon dc conditions. For use in common rectifier circuits Table 1 indicates suggested voltage factors for an equivalent dc voltage to use for conservative design, i.e.

$$V_{R(equiv)} = V_{in(PK)} \times F_V. \qquad (16)$$

Table 1 — Values for Factor F_V

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped*†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

*Note that $V_{RWM} \approx 2\ V_{in(PK)}$ *†Use line to center tap voltage for V_{in}.

The Factor F_V is derived by considering the properties of the various rectifier circuits and the reverse characteristics of the particular diode. At a fixed junction temperature, the reverse power waveform is determined for various peak reverse voltage levels and average power is calculated. From I_R – V_R data the value of V_R, which produces the same power dissipation as in the circuit, is found; it is $V_{R(equiv)}$.

Example: Find $T_{A(max)}$ for the diode of Figure 18 operated in a 24 V dc supply using a bridge circuit with capacitive filter such that the load current $I_{L(DC)} = 10$ A ($I_{F(AV)} = 5$ A), $I_{F(PK)}/I_{F(AV)} = 20$, Input Voltage = 20 V(rms), $R_{\theta JA} = 7$°C/W.

Step 1. Find $V_{R(equiv)}$. Read $F_V = 0.65$ from Table $\therefore V_{R(equiv)} = (1.41)(20)(0.65) = 18.3$

Step 2. Find T_R from Figure 17. Read $T_R = 108$°C @ $V_R = 18.3$ and $R_{\theta JA} = 7$°C/W.

Step 3. Find $P_{F(AV)}$ from rectifier data. $P_{F(AV)} = 10$ W at $I_{PK}/I_{(AV)} = 20$ and $I_{F(AV)} = 5$ A.

Step 4. Find $T_{A(max)}$ from Equation 15. $T_{A(max)} = 108-(7)(10) = 39$°C.

REFERENCES

1. Bill Roehr and Bryce Shiner, "Transient Thermal Resistance – General Data and Its Use," Motorola Application Note, AN-569. Motorola Semiconductor Products Inc., Phoenix, Arizona.

2. Lloyd P. Hunter, et. al., *Handbook of Semiconductor Electronics,* Second Edition, Chapter 11, pp 11-80, 81. McGraw-Hill Book Co., Inc., New York, New York 1962.

CHAPTER 3: RECTIFIER SPECIFICATIONS AND RATINGS

The electrical and thermal characteristics discussed previously are helpful in design work. However, rectifiers are tested by the manufacturer and ratings are based on compliance to given specifications. Therefore, a thorough understanding of specifications and ratings is mandatory if devices are to be used reliably and economically.

Specifications for rectifiers are established by the rectifier JEDEC* committee for registered part numbers, e.g., 1NXXXX numbers. Although non-registered parts do not always conform to the registration specification requirements, the JEDEC specifications generally are used as guidelines. Furthermore, adherence to letter symbols and definitions as developed by JEDEC is widespread, although the symbols and formats have changed in the past and will undoubtedly change in the future. Consequently, although the information is based upon the present status of the JEDEC standards as given in NEMA-EIA publication RS-282, past practices are noted and background information is given so that future changes may be understood.

Table 1 indicates the symbols and terms used to define various voltages and currents used in this chapter. The terms are illustrated by the waveforms of Figure 1 and will be discussed in detail. The table should be studied before proceeding.

Table 1 – JEDEC Letter Symbols for Rectifier Specifications

	VALUE				
	Total rms	Direct-Current Value, No Alternating Component	Direct-Current Value, With Alternating Component	Instantaneous Total	Maximum (Peak) Total
Forward Current	$I_{F(RMS)}$ [I_f]	I_F	$I_{F(AV)}$	i_F	I_{FM}
Average Forward Current, 180° Conduction Angle, 60 cycles per second, Half Sine Wave Current	–	–	I_O	–	–
Peak Repetitive Forward Current	–	–	–	–	I_{FRM} [$I_{FM(rep)}$]
Peak Surge Forward Current	–	–	–	–	I_{FSM} [$I_{FM(surge)}$]
Forward Voltage Drop	$V_{F(RMS)}$ [V_f]	V_F	$V_{F(AV)}$	v_F	V_{FM}
Reverse Current	$I_{R(RMS)}$ [I_r]	I_R	$I_{R(AV)}$	i_R	I_{RM}
Peak Working Reverse Voltage	–	–	–	–	V_{RWM} [$V_{RM(wkg)}$]
Peak Repetitive Reverse Voltage	–	–	–	–	V_{RRM} [$V_{RM(rep)}$]
Peak Non-Repetitive Reverse Voltage	–	–	–	–	V_{RSM} [$V_{RM(non\text{-}rep)}$]
Reverse Breakdown Voltage	–	$V_{(BR)R}$ [BV_R]	–	$v_{(BR)R}$ [bv_R]	–

Terms in brackets are obsolete symbols

*Joint Electron Device Engineering Council of the Electronic Industries Association.

Table 1 — JEDEC Letter Symbols for Rectifier Specifications (Continued)

	VALUE				
	Total rms	Direct-Current Value, No Alternating Component	Direct-Current Value, With Alternating Component	Instantaneous Total	Maximum (Peak) Total
Forward Power Loss	—	P_F	$P_{F(AV)}$		P_{FM}
Reverse Power Loss	—	P_R	$P_{R(AV)}$	p_R	P_{RM}
Junction Temperature	—	T_J	$T_{J(AV)}$	t_J	T_{JM}
Peak Repetitive Junction Temperature	—	—	—	—	T_{JRM}
Forward Current Flowing					T_{JFRM}
Reverse Voltage V_{RWM} Applied					T_{JRRM}
Peak Surge Junction Temperature	—	—	—	—	T_{JSM}

Note: Junction Temperature notations are not approved JEDEC Standards.

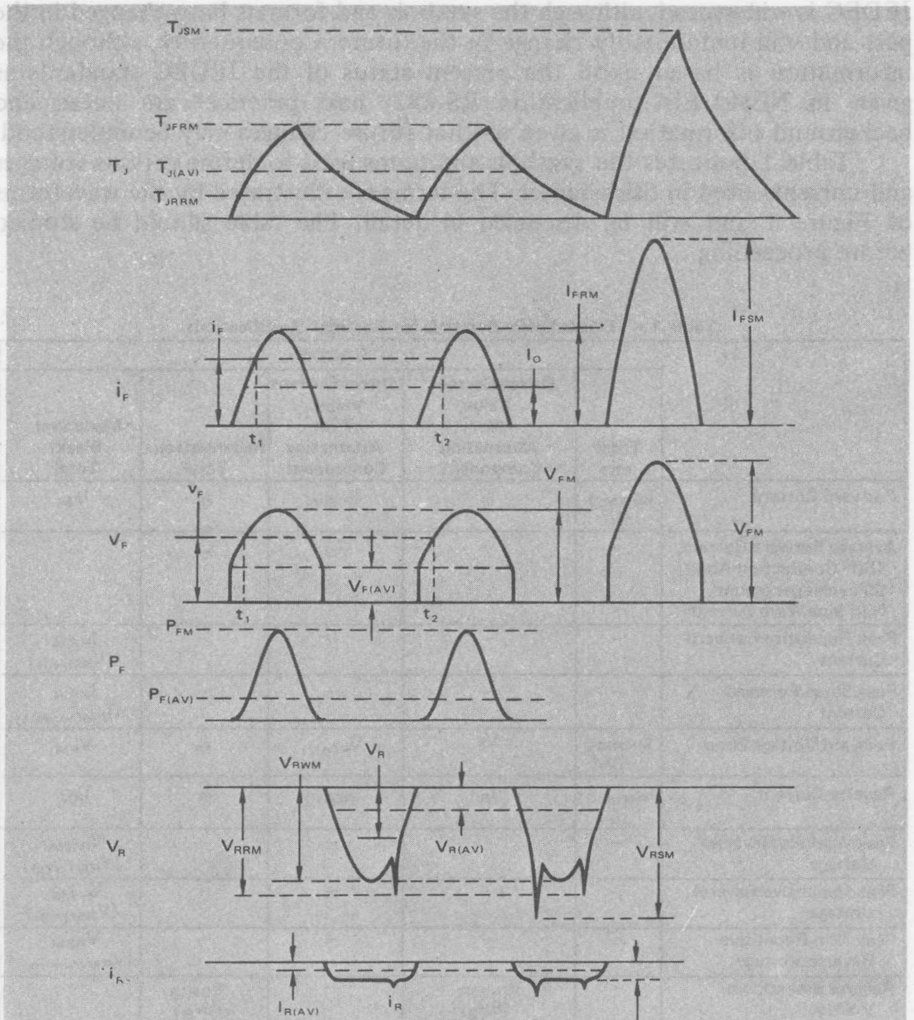


Figure 1 — Illustration of symbols for reverse and forward Voltage and Current and Junction Temperature Excursion resulting from the developed power.

SPECIFIED ELECTRICAL CHARACTERISTICS

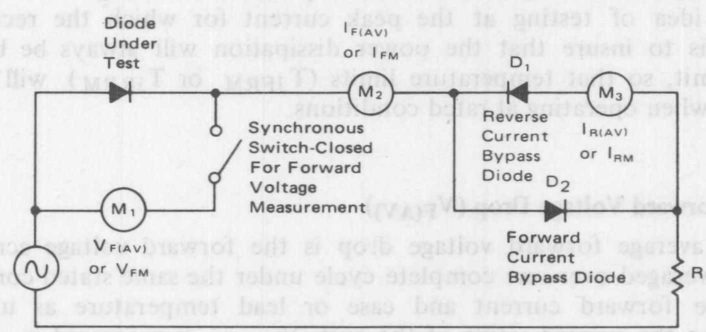
Because the major use of rectifiers is in the conversion of 60 Hz supply line voltage to direct current, the JEDEC required specifications until recently consisted simply of a current rating, a voltage rating, and some measurement of reverse current and forward voltage. Presently thermal and reverse recovery data is also required on all rectifiers. Graphs of the characteristics specified, showing the effect of voltage, current, and temperature, are frequently given on manufacturers' data sheets.

Various specifications (generally referred to as specs) in common use will be examined in this section. Their main purpose is to insure that the rectifier meets its current and voltage ratings.

Maximum or Peak Reverse Current (I_{RM})

The maximum reverse current is the peak reverse current through the rectifier at its rated reverse voltage (V_{RWM}) and maximum operating temperature, i.e., the case or lead temperature at which the current is derated to zero. If reverse power is negligible, the maximum operating temperature is equivalent to T_{JRRM}.

The current I_{RM} is generally measured using a pulse technique for production convenience because it can be done quickly and offers no problems with thermal runaway. The dynamic load test circuit of Figure 2 may also be used, but if accurate data is to be retrieved, the diode will have to be mounted on a substantial heat sink having some external means of controlling the case temperature to within a few degrees. If temperature control is not used, differences in forward power dissipation between parts will cause significant changes in case and junction temperature. The resulting data would be useless because of the strong dependance of I_R upon T_J.



TEST NOTES:

1. Circuits must be devised so that meter M_1, is not subjected to the reverse half cycle.
2. For average readings, meters M_2 and M_3 should be permanent magnet moving-coil-type direct-current instruments.
3. Diode D_1 may be a low-current low-voltage type.
4. Diode D_2 must handle the forward current of the diode under test but its reverse characteristic is unimportant.

Figure 2 — Dynamic Load Test Circuit which may be used for forward and reverse characteristics (See Chapter 11 for further information).

Average Reverse Current ($I_{R(AV)}$)

The average reverse current is the value of reverse leakage current averaged over one complete cycle under the stated conditions of forward current, reverse voltage, and case temperature. Although this specification serves as a comparison of the rectifier to an ideal switch of zero leakage in open position, $I_{R(AV)}$ must be measured in the dynamic load test circuit (Figure 2) with its attendant problems as discussed above.

DC Reverse Current (I_R)

The dc reverse current is the value of reverse current through the rectifier under stated conditions of rated dc reverse voltage (V_R) and case temperature. The temperature specified was formerly required by JEDEC to be at the maximum operating temperature but, because of thermal runaway problems, it may now be specified at a lower temperature. DC reverse current at room temperature is generally added to the JEDEC specification requirements by manufacturers because it yields a quick check of rectifier quality, but it is not significant in the establishment of the ratings.

Maximum or Peak Forward Drop (V_{FM})

The maximum forward drop is the peak forward voltage across the rectifier under the same stated conditions of current and case or lead temperature used for the current rating (I_O). V_{FM} may be measured using the dynamic circuit of Figure 2 or by a pulse technique to keep junction heating negligible. Using the dynamic circuit, the temperature of the heat sink must be controlled by external means so that variations in power dissipation between parts do not influence case temperature. With the pulse method, no heat sink or complicated temperature control is necessary and, consequently, it is more practical to use in production testing.

The idea of testing at the peak current for which the rectifier is specified is to insure that the power dissipation will always be below a certain limit, so that temperature limits (T_{JFRM} or T_{JRRM}) will not be exceeded when operating at rated conditions.

Average Forward Voltage Drop ($V_{F(AV)}$)

The average forward voltage drop is the forward voltage across the rectifier averaged over one complete cycle under the same stated conditions of average forward current and case or lead temperature as used for establishing the current rating of the part. $V_{F(AV)}$ is measured in a circuit similar to that for V_{FM} shown in Figure 2 except that a dc meter is used instead of a peak reading meter.

As discussed above, temperature control is a problem; furthermore, this measurement does not necessarily guarantee that the power dissipation will be below the limit necessary to keep temperature limits from being exceeded. This problem is illustrated by the sketch of Figure 3. Two rectifiers having different forward characteristics are shown by curves 1 and 2. Both have the same $V_{F(AV)}$ but the rectifier of curve 2 has a higher V_{FM}; it will have higher power dissipation than rectifier 1.

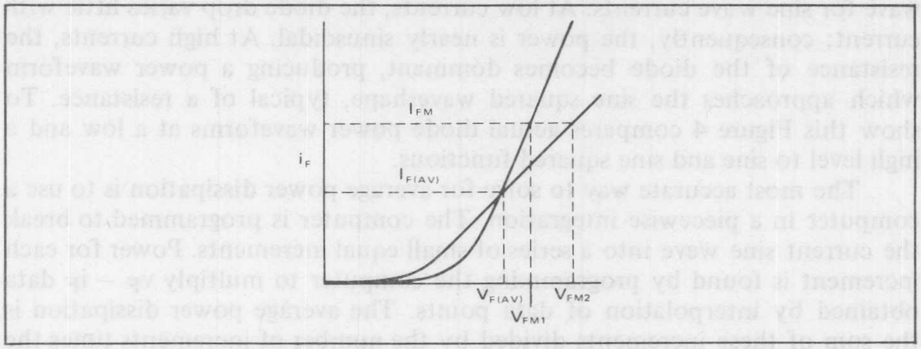


Figure 3 – Two Rectifier Forward Voltage Curves showing difficulty of controlling rectifier power dissipation by limiting average voltage

DC Forward Voltage Drop (V_F)

The dc forward voltage drop is the forward voltage across the rectifier under the stated conditions of dc current and case temperature. This specification has gained widespread popularity for in-house part numbers since it requires only simple test equipment, but it suffers even worse than the $V_{F(AV)}$ specification in controlling V_{FM} and in requiring temperature control for accuracy. A specification at room temperature and low I_F is often added to the minimum JEDEC requirements for use as a quick simple check of rectifier quality, but it plays only an indirect part in the ratings.

FORWARD POWER DISSIPATION

For convenience of the designer, data sheets usually show a plot of average forward power dissipation versus average forward current for various conduction angles. Data can be obtained by measurement or values may be obtained by using one of several methods of calculation. The methods trade off accuracy for simplicity and range from the watt per amp "rule of thumb"* to integration techniques requiring the use of a computer.

Power dissipation may be measured by utilizing the thermal resistance of the heat sink system. A thermocouple is attached to a convenient place on the rectifier case or the heat sink, and the ac current is applied to the input of a suitable rectifier circuit, preferably the one intended for end-use. The temperature and average current levels are recorded after thermal stability is achieved. Next dc current is applied and its level adjusted until the temperature equals that obtained during the previous measurement. The forward drop is now easily measured and used to compute power. This measurement technique is particularly useful when operation is desired at frequencies where the transient power losses of the diode must be considered.

Calculation of ac power losses is complicated by the non-linear V-I characteristic of semiconductor diodes. If diodes were to have a constant voltage drop with current, the power waveform would naturally be a sine

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*The watt per amp "rule of thumb" is based on the assumption that for any given value of average current, the average forward voltage is one volt. This approximation is conservative at small forward currents and optimistic at the high values. It does, however, provide a reasonable guess of average power without knowing the forward voltage characteristic, providing the conduction angle is 180°.

wave for sine wave currents. At low currents, the diode drop varies little with current; consequently, the power is nearly sinusoidal. At high currents, the resistance of the diode becomes dominant, producing a power waveform which approaches the sine squared waveshape, typical of a resistance. To show this Figure 4 compares actual diode power waveforms at a low and a high level to sine and sine squared functions.

The most accurate way to solve for average power dissipation is to use a computer in a piecewise integration. The computer is programmed to break the current sine wave into a series of small equal increments. Power for each increment is found by programming the computer to multiply $v_F - i_F$ data obtained by interpolation of data points. The average power dissipation is the sum of these increments divided by the number of increments times the period of the waveform. Accuracy improves with the number of increments used. As a guide, average power dissipation will be accurate to better than 1 percent if the wave is broken into 20 equal increments and 25 data points are used to define the forward voltage curve.

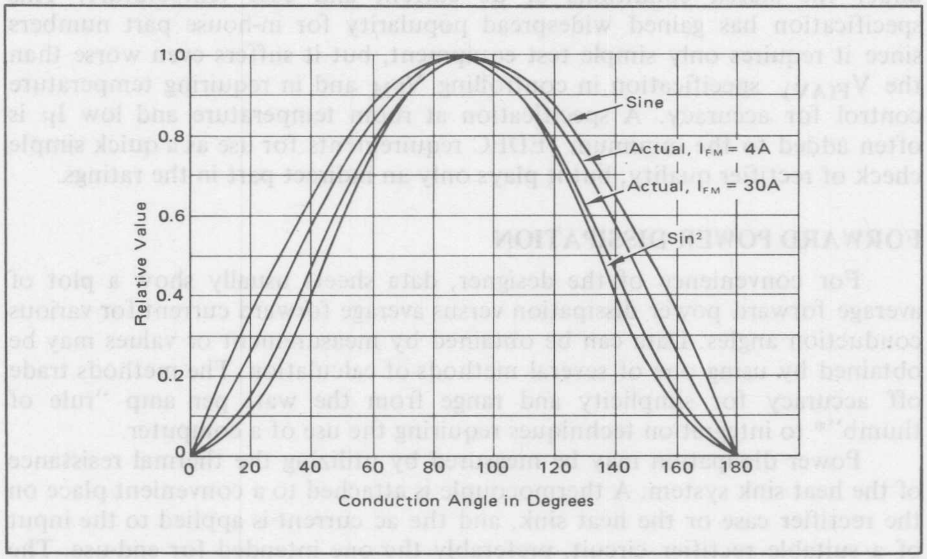

Figure 4 – Actual Diode Power Waveforms Compared to Sine and Sine Squared Waveforms.

Another method of obtaining average power dissipation is to approximate the forward voltage curve with an offset voltage and a straight line as shown in Figure 5; thus $V = V_O + mi$, where m is the dynamic resistance of the diode.

Since $i = I_M \sin \theta$,

$$P_{F(AV)} = \frac{1}{2\pi}\int_O^{\pi} iv\,d\theta \tag{1}$$

$$= \frac{1}{2\pi}\left[\int_O^{\pi} V_O I_M \sin\theta + \int_O^{\pi} mI_M^2 \sin^2\theta\right] d\theta .$$

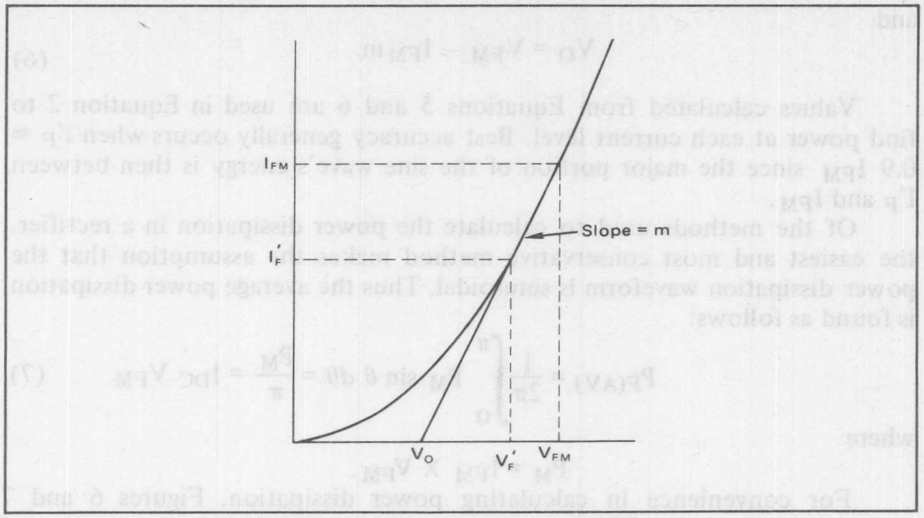

Figure 5 — Approximation of a diode forward characteristic for accurate calculation of power loss when handling a sinusoidal current waveform.

Solving, find

$$P_{F(AV)} = \frac{V_O I_M}{\pi} + \frac{mI_M^2}{4} \tag{2}$$

Since $i_{RMS} = 0.5\ I_M$,

$$P_{F(AV)} = V_O I_{(DC)} + mI^2_{(RMS)} \tag{3}$$

or, since the form factor, $F = I_{RMS}/I_{DC}$,

$$P_{F(AV)} = I_{DC}\ (V_O + mI_{DC}\ F^2). \tag{4}$$

Thus, it is readily seen that waveforms with a high form factor or rms content cause a higher power dissipation in the rectifier diode than an equivalent direct current.

The offset voltage-straight line approximation is good when the forward voltage is in the linear region of the v_F - i_F curve. In the non-linear or exponential region this approach can be used if a different slope and offset are determined for each value of forward current. Such a determination is an ideal task for a computer. The result is nearly as accurate as piecewise integration, but the program requires considerably less computer time.

The computer is fed v_F – i_F data and programmed to linearly interpolate between points as in the piecewise method. Based on the sine wave peak value and a percentage of peak value, the computer solves for two v_F values, i.e., for I_{FM} and I'_F find V_{FM} and V'_F as shown in Figure 5. Using these two values of forward voltage the slope and offset voltage are found from:

$$m = \frac{V_{FM} - V'_F}{I_{FM} - I'_F} \tag{5}$$

and

$$V_O = V_{FM} - I_{FM} m. \tag{6}$$

Values calculated from Equations 5 and 6 are used in Equation 2 to find power at each current level. Best accuracy generally occurs when $I'_F \approx 0.9\ I_{FM}$ since the major portion of the sine wave's energy is then between I'_F and I_{FM}.

Of the methods used to calculate the power dissipation in a rectifier, the easiest and most conservative method makes the assumption that the power dissipation waveform is sinusoidal. Thus the average power dissipation is found as follows:

$$P_{F(AV)} = \frac{1}{2\pi}\int_O^{\pi} P_M \sin\theta\, d\theta = \frac{P_M}{\pi} = I_{DC}\ V_{FM} \tag{7}$$

where

$$P_M = I_{FM} \times V_{FM}.$$

For convenience in calculating power dissipation, Figures 6 and 7 permit form factor and peak to average values to be found for a number of commonly used waveforms.

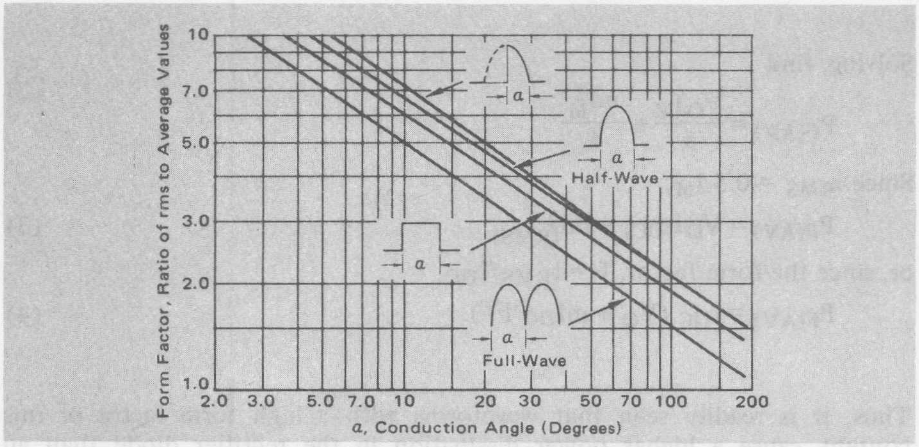

Figure 6 — Form Factor for Various Current Waveforms.

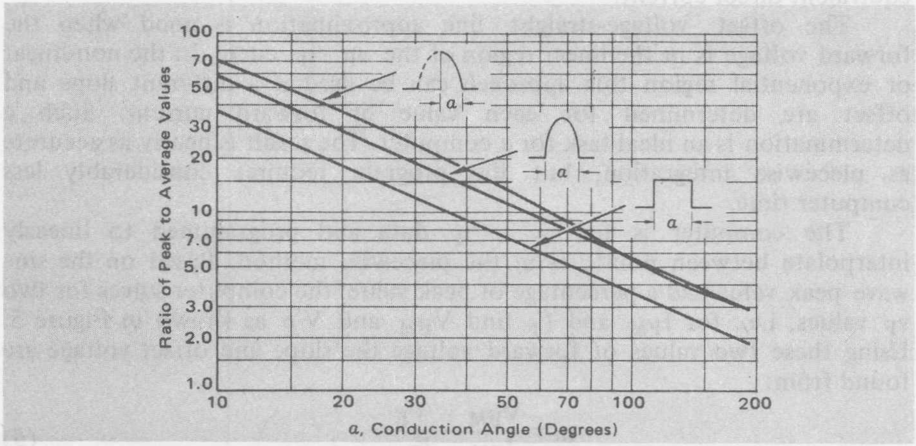

Figure 7 — Peak to Average Ratios for Various Current Waveforms.

THERMAL AND MECHANICAL RATINGS

Temperatures

The maximum and minimum storage temperatures (T_{stg}) simply define the temperature range allowable during storage. Excessively hot temperatures can damage the die-to-case bond or cause alteration in characteristics which would result in a field failure, even though the device is not operating. Excessively cold temperature can cause cracking of the crystal with subsequent voltage degradation or catastrophic failure. Minimum operating temperatures are usually the same as minimum storage temperatures.

The maximum repetitive peak temperature T_{JRRM} is the temperature at which the device was classified for V_{RRM}. The maximum peak values T_{JSM} and T_{JFRM} though generally not stated, are factors in determining the surge ratings and the average current ratings with capacitive loads which impose a high peak-to-average current ratio upon the rectifier. The peak values are useful in calculating acceptable limits of junction temperature under transient or pulsed conditions and recently (1973) T_{JFRM} was made a mandatory requirement on JEDEC registered part numbers.

Stud Torque

The maximum stud torque limit is the allowable torque which may be applied to the threaded portion of the stud in a dry-friction condition without damage to either the rectifier die or the case. By using a value of torque close to the limit, the rectifier can be mounted for minimum thermal resistance between the rectifier case and the heat sink. See Chapter 10 for further information.

Fusing

The maximum current-squared-seconds (I^2t) is that maximum value of the forward nonrecurring overcurrent capability for times between 1.0 and 8.3 milliseconds. The protective fusing element in the rectifier circuit should have an I^2t value less than the rectifier, so that the circuit opens before the rectifier can be damaged. For further information, see the overcurrent protection section of Chapter 9.

VOLTAGE RATINGS

Voltage ratings are not a characteristic; they cannot be measured but are stated by the device manufacturer over the entire temperature and operating range for the life of the device. Ratings should not be exceeded under any circumstances. All ratings are referenced to a half-wave 60-hertz rectifier circuit using a resistive load, unless otherwise specified.

The first three ratings to be discussed are generally all the same for rectifiers. Although the theoretical basis of peak reverse voltage ratings is the maximum reverse power generation permissible before thermal runaway* is reached, these ratings are frequently limited for other reasons, such as an abrupt change in slope of the V/I curve, hysteresis, discontinuities excluding

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*Voltage ratings generally apply when maximum rated forward current is flowing. Under this condition the thermal resistance, junction-to-ambient is necessarily rather low. As discussed in Chapter 2, thermal runaway can occur well below rated voltage if $R_{\theta JA}$ and T_A are relatively high.

sharp knees, surface effects, or instability of the V/I curve. Voltage ratings are generally well below avalanche breakdown voltage but it may be a limiting factor at low temperatures.

The equipment designer has the responsibility for determining that none of the reverse voltage ratings of the device are exceeded under any possible combination of operating, test, or environmental conditions. If voltages exceeding any of the reverse voltage ratings are applied to the rectifier diode, a markedly increased probability of failure will exist. The ratings do not imply any safety factor. Figure 1 illustrates the various voltages discussed.

Peak Repetitive Reverse Voltage (V_{RRM})

The peak repetitive reverse voltage is the maximum allowable instantaneous value of the reverse voltage, including all repetitive transient voltages, but excluding all non-repetitive transient voltages which occur across a rectifier diode.

The peak repetitive reverse voltage occurs in a rectifier connection due to rectifier diode properties in conjunction with circuit constants and is, to some extent, under the control of the equipment designer. This is a periodic voltage which includes effects such as commutation, inductive kicks, etc.

Peak Working Reverse Voltage (V_{RWM})

The peak working reverse voltage is the maximum allowable instantaneous value of the reverse voltage which occurs across a rectifier diode, excluding all repetitive and non-repetitive transient voltages. The input voltage to the circuit must be such that the PIV applied to the rectifier does not exceed this voltage. The rating is generally based upon operation in a half-wave 60 Hz rectifier circuit with resistive load.

DC Reverse Blocking Voltage (V_R)

The maximum dc reverse blocking voltage is the maximum allowable value of the reverse voltage, excluding all repetitive and non-repetitive transient voltages, across a rectifier diode. This specification is no longer used. Values for the dc rating are usually the same as V_{RWM}.

Peak Non-repetitive Reverse Voltage (V_{RSM})

The peak non-repetitive reverse voltage is the maximum allowable instantaneous value of reverse voltage across the rectifier, including all non-repetitive transient voltages but excluding all repetitive transient voltages.

The non-repetitive peak reverse voltage occurs as a random circuit transient which may or may not originate within the equipment. This voltage may often be minimized by the provision of voltage surge-suppression components, as discussed in Chapter 9.

CURRENT RATINGS

Of paramount importance are a rectifier's current ratings. Current ratings are conditional ratings – dependent upon the rectifier's case or lead

temperature and the waveform being handled. In this way, they differ from voltage ratings, which apply over the full temperature range of the part (unless thermal runaway enters the picture), and waveform doesn't usually matter.

There are several temperature limits which are effective in limiting the current which a rectifier may handle. Some may be seen on Figure 1 which shows the junction temperature of a rectifier operating in a resistively loaded half-wave, single-phase circuit under steady state conditions prior to a current surge.

The repetitive peak junction temperature, T_{JFRM} sets one limit upon rectifier current ratings. If exceeded the die bond may be weakened, resulting in an eventual field failure. The limit of T_{JFRM} depends upon the manufacturers' assembly technique. The temperature caused by the circuit depends upon the amplitude and waveshape of the pulse train and the transient thermal impedance of the rectifier.

Another limit is set by T_{JRRM} (often called $T_{J(max)}$, which is the temperature used for determining the voltage rating. Note that T_{JRRM} is under $T_{J(AV)}$ for the waveform being considered. In practice T_{JRRM} and $T_{J(AV)}$ are close together.

A third limit on the rectifier current rating is the temperature at which the lead material from the die to the terminal fuses or becomes excessively hot. Lead temperature is a function of the lead material resistivity and the rms value of forward current ($T_L \propto I^2R$).

The junction temperatures, T_{JFRM} and T_{JRRM}, and the lead fusing temperature must all be considered in determining a rectifier rating. Since one or the other will limit current at different operating conditions, manufacturers often provide curves to aid in determining satisfactory operating limits.

A final temperature limit is the peak surge junction temperature, T_{JSM}. If the surge is only allowed a few times (few being defined by JEDEC as less than 100) during a rectifier's life, then no harm results providing the surge is limited. The surge temperature is the basis for the I_{FSM} rating.

Average Forward Current (I_O)

It is customary, as well as a JEDEC requirement, to rate rectifiers in terms of average current delivered to a resistive load at a specified case temperature in a 60 Hz half-wave circuit. The rated current is defined as I_O. The basis for this rating is that t_J is below T_{JRRM} when V_{RWM} is applied. (At Motorola, the I_O rating is developed by a computer program which sets $t_J = T_{JRRM}$ at a time 1 ms after forward conduction ceases. Worst case values for $R_{\theta JC}$ and V_F are used). The case temperature used for the I_O rating is required by JEDEC to be 100°C or higher for case-mounted rectifiers and the lead temperature is 70°C or higher for lead-mounted rectifiers.

It is safe to assume that I_O is truly an rms limit when estimating current ratings for capacitive loads or other loads having a high form factor (ratio of rms to average current); however, such an assumption may unduly restrict the usefulness of a particular rectifier. Form factor and peak-to-average ratio data are shown in Figures 6 and 7 as functions of conduction angles for commonly encountered rectifier waveforms. The data is useful in establishing current ratings for conditions other than the ones specified.

Figure 8 is an example of current derating data for a stud- or case-mounted rectifier. The dc (rms) limit is called out at 39.3 amperes. A check of the curve data against the data of Figures 6 and 7 reveals that the flat portion of the curves shows the same rms limit, e.g., for $I_{FM}/I_{F(AV)} = 20$, read $\alpha = 28^\circ$ from Figure 7. At this angle, read $F \approx 3.9$ from Figure 6. $\therefore I_{F(AV)} \approx 39.3/3.9 \approx 10$ A which agrees with curve 6. Consequently, derating curves for waveforms other than the ones shown could easily be determined by using the data of Figures 4 and 5 to obtain the rms limit and using the given derating curves as a guide.

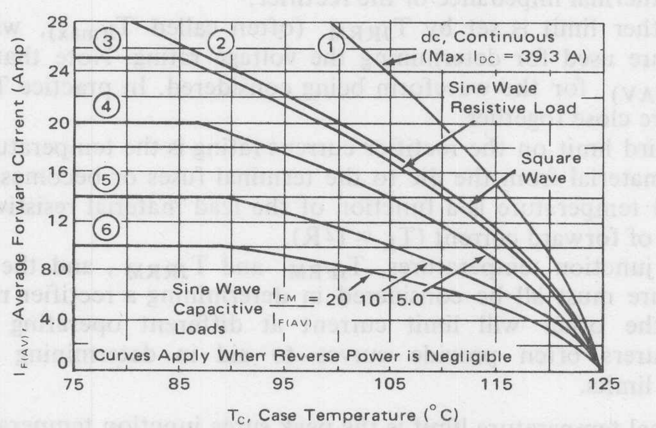


Figure 8 — Example of Current Derating Data where RMS limits are evident as flat portions of the curves (from 1N5829 Data Sheet).

As mentioned previously, the sine wave derating data is based upon $t_J = T_{JRRM}$ at a time 1ms after cessation of forward conduction. The dc derating curve, curve (1) on Figure 8 and the square wave derating curve, curve 2, are based upon T_{JFRM} because the reverse voltage generally appears immediately after forward conduction ceases. Note that the square wave curve, curve 2, is very close to the sine wave resistive load derating data; however, the average current limit is at 28 amperes since $I_{(RMS)} = 1.41\ I_{(AV)}$ for a square wave.

Derating data for a lead-mounted rectifier is shown in Figure 9. Since no rms limit is indicated, it can be assumed that it is greater than (3.9)(4.3) or 18.5 amperes by using data for $I_{FM}/I_{(AV)} = 20$ from Figures 6, 7, and 9. Therefore, other waveforms having an rms value below 18.5A could be safely handled by the rectifier. For these other waveforms, it would be well to use thermal response data to check for T_{JFRM} to insure it is within a reasonable limit by using the technique outlined in Chapter 2.

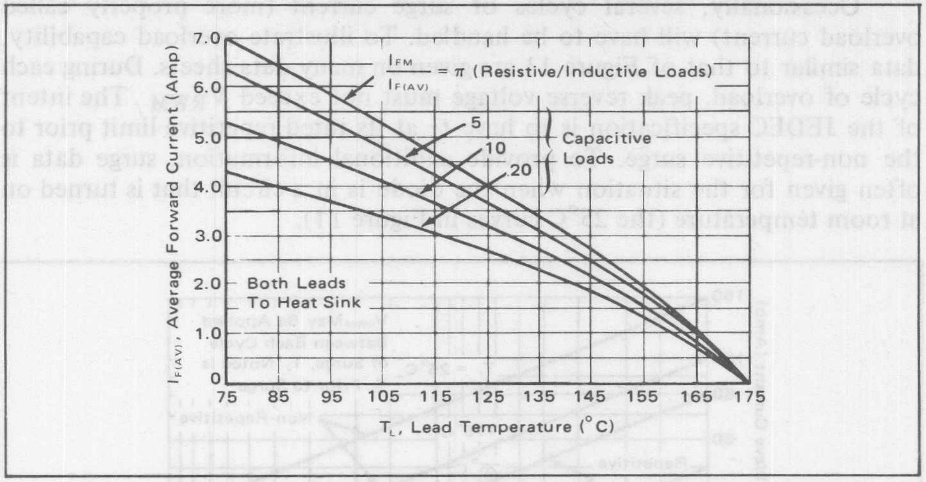


Figure 9 – Example of Current Derating Data for a rectifier which does not show an RMS Limit (From MR501 Data Sheet).

Peak Surge Forward Current (I_{FSM})

The maximum allowable surge current is the peak current that the rectifier can safely handle for a minimum of 100 times in its lifetime. It is a non-repetitive rating in the sense that the surge may not be repeated until thermal equilibrium conditions have been restored.

An illustration of the JEDEC specified conditions is shown in Figure 10. The rectifier is subjected to rated voltage and current until thermal equilibrium is established. One half-cycle of surge current, I_{FSM} , is applied, followed by one half-cycle of non-repetitive rated-voltage, V_{RSM} . If the junction temperature is driven too high by the current, thermal runaway will occur and the rectifier will be destroyed.

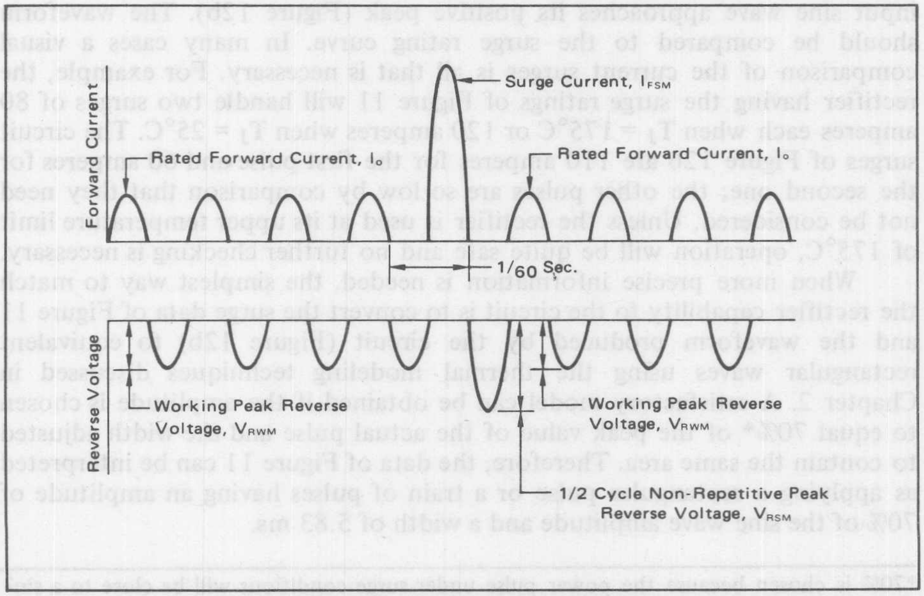


Figure 10 – Conditions for the JEDEC Surge Current Specification

Occasionally, several cycles of surge current (more properly called overload current) will have to be handled. To illustrate overload capability, data similar to that of Figure 11 are given on many data sheets. During each cycle of overload, peak reverse voltage must not exceed V_{RWM}. The intent of the JEDEC specification is to have t_J at its rated repetitive limit prior to the non-repetitive surge. To provide additional information, surge data is often given for the situation when the diode is in a circuit that is turned on at room temperature (the 25°C curves in Figure 11).

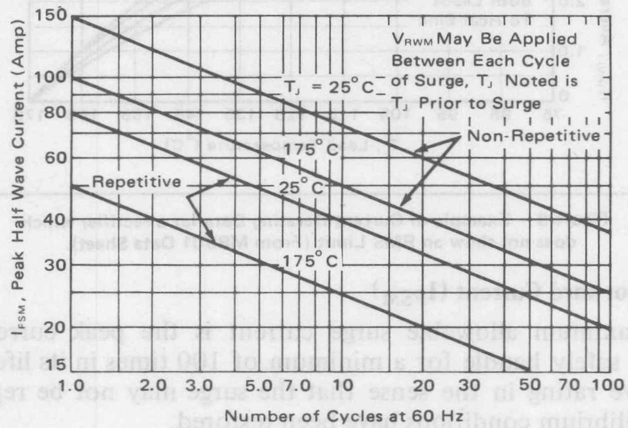


Figure 11 – Example of Surge Current Data (applies for MR501, MR850 Series)

A common use for surge data is to check rectifier operation in a line operated circuit with a capacitive input filter, as shown by the circuit of Figure 12a. Worst case current surges occur when the switch is closed as the input sine wave approaches its positive peak (Figure 12b). The waveform should be compared to the surge rating curve. In many cases a visual comparison of the current surges is all that is necessary. For example, the rectifier having the surge ratings of Figure 11 will handle two surges of 80 amperes each when T_J = 175°C or 120 amperes when T_J = 25°C. The circuit surges of Figure 12b are 110 amperes for the first pulse and 60 amperes for the second one; the other pulses are so low by comparison that they need not be considered. Unless the rectifier is used at its upper temperature limit of 175°C, operation will be quite safe and no further checking is necessary.

When more precise information is needed, the simplest way to match the rectifier capability to the circuit is to convert the surge data of Figure 11 and the waveform produced by the circuit (Figure 12b) to equivalent rectangular waves using the thermal modeling techniques discussed in Chapter 2. A satisfactory model can be obtained if the amplitude is chosen to equal 70%* of the peak value of the actual pulse and the width adjusted to contain the same area. Therefore, the data of Figure 11 can be interpreted as applying a rectangular pulse or a train of pulses having an amplitude of 70% of the sine wave amplitude and a width of 5.83 ms.

*70% is chosen because the power pulse under surge conditions will be close to a $\sin^2$ function.

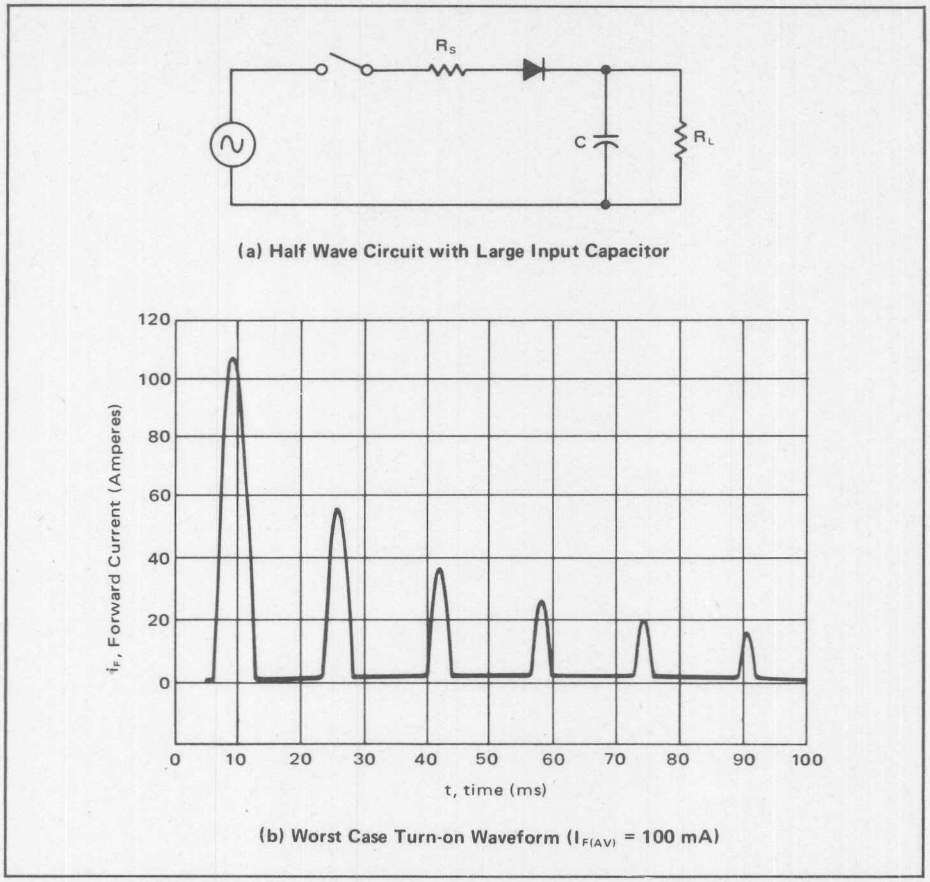


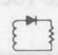
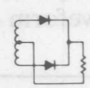
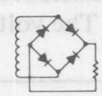
Figure 12 – Start Up Transients in a Half Wave Line Operated Rectifier Circuit

Using the methods of calculating instantaneous junction temperature presented in Chapter 2, the maximum temperatures at the end of the power pulse and at the time when the reverse voltage reaches its peak may be calculated for the rectifier data and for the circuit. If the temperature allowed during surge is higher than that produced by the circuit, satisfactory operation can be assumed.

CHAPTER 4: BASIC SINGLE-PHASE RECTIFYING CIRCUITS

Rectification of alternating current is an old and important application which arises because it is more simple and economical to generate and distribute electric energy as alternating current, but many applications of electric energy require the use of unidirectional or direct current. Applications requiring the use of direct current include supplying power to electronic circuits, electroplating, chemical processing, welding, charging of storage batteries, operating series railway motors, and running adjustable speed dc motors.

In this chapter, basic characteristics of single-phase circuits with resistive loads will be discussed. Polyphase circuits are treated in Chapter 5; filter design follows in Chapter 6. Results of all the calculations in this chapter are presented in Table 1.

RECTIFIER CIRCUIT CONNECTION	HALF-WAVE 	FULL-WAVE CENTER-TAP 	FULL-WAVE BRIDGE 
LOAD VOLTAGE and CURRENT WAVESHAPE			
CHARACTERISTIC			
Diode Average Current $I_{F(AV)}/I_{L(DC)}$	1.00	0.50	0.50
Diode Peak Current $I_{FM}/I_{F(AV)}$	3.14	3.14	3.14
Form Factor of Diode $I_{F(RMS)}/I_{DC}$	1.57	1.57	1.57
Diode RMS Current $I_{F(RMS)}/I_{L(DC)}$	1.57	0.785	0.785
RMS Input Voltage Per Transformer Leg $V_i/V_{L(DC)}$	2.22	1.11	1.11
Peak Inverse Voltage $V_{RRM}/V_{L(DC)}$	3.14	3.14	1.57
Transformer Primary Rating VA/P_{DC}	3.49	1.23	1.23
Transformer Secondary Rating VA/P_{DC}	3.49	1.75	1.23
Total RMS Ripple, %	121	48.2	48.2
Lowest Ripple Frequency, f_r/f_i	1	2	2
Rectification Ratio (Conversion Efficiency), %	40.6	81.2	81.2

Note: $P_{DC} = I^2_L\ R_L$ (R_S neglected) $V_L = I_L R_L$

Table 1: Characteristics of Basic Single-Phase Rectifier Circuits with Resisitive Loads

BASIC OPERATION

When considering any rectifying circuit, a designer desires to know the magnitude of the direct voltage and current, the regulation of the load voltage, and the efficiency to be expected from the rectifying process. All these values depend upon a number of variables – such as the type of circuit, the constants of the supply, the characteristics of the rectifying unit, and the nature of the load – which complicate the analytical solution. However, it is possible to make certain assumptions which reduce the circuit to an ideal basis from which a useful analysis can be made.

The simplest circuit for rectifying single-phase alternating current gives half-wave rectification. Such a circuit is indicated in Figure 1a, where the bold-faced arrow represents the rectifying unit and the direction of conventional current flow. Assume (1) an ideal source without resistance and having a constant voltage, (2) the impressed emf is a pure sine wave, (3) the rectifying unit has zero resistance in the forward direction of current and infinite resistance in the reverse direction, and (4) the load is a pure ohmic resistance. With these assumptions, let a sine wave alternating voltage as shown in Figure 1b be impressed across the input to the rectifying circuit. The output is a rectified half-wave of current as indicated in Figure 1c, which is of a sine form, since $i = (V_M/R_L) \sin \omega t$. During the second half of the cycle the rectifier will block current. The current flowing through the load resistance R_L will produce an iR_L voltage drop which is a half sine wave form. The voltage waveform across the rectifier is shown by Part e.

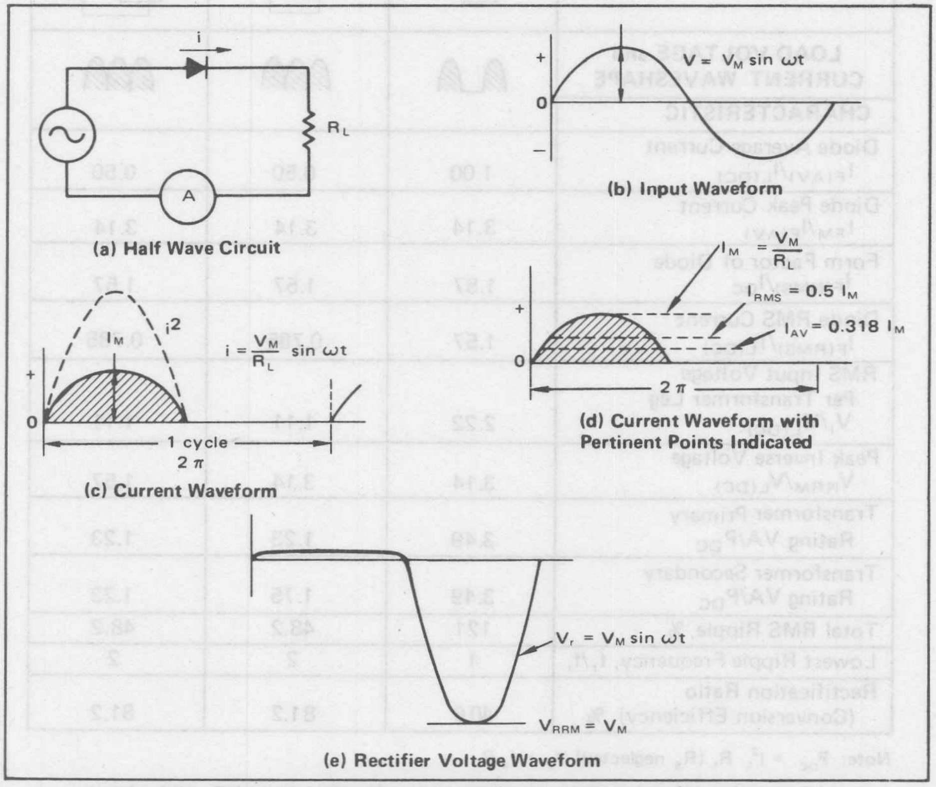


Figure 1 – Circuit and wave shapes for half-wave rectification. (Rectifier diode forward voltage drop and reverse current are neglected)

CURRENT RELATIONSHIPS

Since the function of rectification is to convert alternating current to direct current, the equivalent value of the direct current output is of primary interest. Its value will be measured by a dc ammeter placed in the circuit of Figure 1a.

This dc value is the average value of the instantaneous rectified current over one cycle or a period corresponding to 2π radians. Average values can be determined by a graphical and arithmetic process by measuring the instantaneous value of current at a series of equally spaced points along the time axis and then dividing the sum of these values by the total number of points in a cycle. A more accurate solution may be obtained by measuring the area under the rectified current pulse and dividing by 2π. The more direct solution is to apply the mathematics of calculus to the problem; thus:

$$I_{DC} = I_{AV} = \frac{1}{2\pi}\int_{O}^{\pi} I_M \sin \omega t \, d(\omega t). \quad (1)$$

Solving,

$$I_{DC} = \frac{2I_M}{2\pi} = 0.318\, I_M. \quad (2)$$

An ac ammeter inserted in the rectifying circuit of Figure 1a gives a different reading from the dc meter first considered. This difference arises because the ac meter registers effective or root-mean-square (rms) values* rather than average values. The heating or effective value of a current varies as the square of the instantaneous current. Hence to determine the effective value of the rectified current graphically, it is first necessary to plot squared values of the instantaneous current as suggested by the dotted i^2 curve on Figure 1c. The effective area under the dotted i^2 curve may be obtained by the graphical point method or by calculus; thus:

$$\text{Effective area} = \int_{O}^{\pi} I_M^2 \sin^2 \omega t d(\omega t) \quad (3)$$

$$= I_M\left[\frac{\omega t}{2} - \frac{\sin 2\,\omega t}{4}\right]_{O}^{\pi} = \frac{I_M 2\pi}{2}$$

and the effective or rms current, $I_{RMS} = \sqrt{\frac{\text{effective area}}{2\pi}} = 0.5 I_M$. (4)

The average and effective values of rectified current for the half-wave circuit are indicated in Figure 1. The integration of equations 1 and 3 are the standard procedures for obtaining the average and effective values of periodic functions.

*To measure accurately, an ammeter which responds to true rms values must be used. Most ac meters are actually average responding instruments with appropriate scale multipliers to obtain an rms indication.

Because the dc component of output current must flow through the transformer, its core is magnetized and high core losses result. Half-wave circuits are therefore not used with transformers unless current requirements are small. However, it is a very popular circuit for direct line rectification.

Two types of circuits are used for full-wave, single-phase rectification. One circuit uses a transformer with a mid-tap in the secondary winding, as shown in part (a) of Figure 2. The other uses a bridge configuration, shown in part (b) of Figure 2, which requires two extra rectifier diodes, but the secondary requires only half as much winding. Circuit operation is nearly identical. The only other difference is that the bridge rectifiers are subjected to only half the peak inverse voltage of the center-tap circuit (to be discussed later). Since both half-waves of current pass through the transformer (dividing in the secondary of the center-tap circuit), there is no dc component of flux in the transformer core to increase core losses.

Using the same assumptions made for the preceding half-wave rectifier circuit, the relation between the input and output sides of either full-wave rectifier circuit may be readily calculated. Since both halves of the cycle are rectified, the current and voltage on the input side are normal effective values; rms values on the output side are the same as for a sine wave while the dc or average values are twice that of a half-wave circuit. The relationships are shown in Figure 2d.

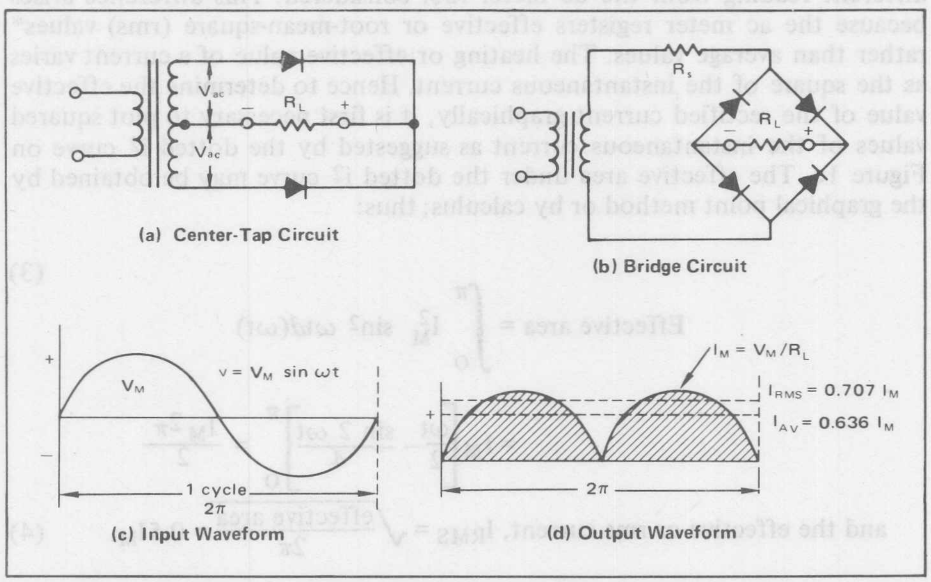


Figure 2 – Circuits and waveshapes for full-wave rectification.

FORM FACTOR

Rectifier circuit efficiencies can be related to a quantity termed Form Factor (F). It is the ratio of the heating component of a wave to the dc component, i.e.,

$$F = \frac{I_{(RMS)}}{I_{(AV)}} \tag{5}$$

Substituting the values from Equations 2 and 4 into 5, the form factor for a half-wave circuit is 1.57. It is the same for each rectifier element in the full-wave systems because each side conducts on opposite half cycles.

Form factor takes on significance when rectifiers must handle high peak currents at low duty cycles, since the power losses in the diodes and transformers are much higher than encountered with sine wave pulses. Applications where high form factors are the rule occur when capacitive input filters are used, when batteries are being charged, and when rectifiers are used with SCRs in phase control circuitry.

UTILIZATION FACTOR

Because of the waveforms involved in rectifier circuits, transformers are not used as efficiently as when they handle pure sinusoidal waveforms. A measure of rectifier circuit merit is the utilization factor (UF), defined as the ratio of the dc output power to the transformer volt-ampere rating required by the primary and/or the secondary.

For the circuits in this chapter, the UF can be found by using the relationships between rms and average current. As defined,

$$UF = \frac{I_{AV}\ V_{AV}}{I_{RMS}\ V_{RMS}}\ . \tag{6}$$

For the half-wave circuit

$$UF = (0.318\ I_M)\ V_{DC}/(0.5 I_M)(2.22\ V_{DC}) = 0.286.$$

For a full-wave circuit, transformer utilization is much improved because conduction is continuous. In the center-tap circuit, it must be considered that although both windings are present only one is used at a time. The utilization factor for the secondary is found as

$$UF = \frac{(0.318\ I_M)\ (2)\ V_{DC}}{2\ (0.5\ I_M)\ (1.11)\ V_{DC}} = 0.572.$$

In the primary, the whole winding is naturally in continuous use; the input power is, assuming a 1:1 winding for simplicity, $(\sqrt{2}/2) I_M \quad V_{i(RMS)}$. Therefore,

$$UF = \frac{(0.318\ I_M)\ (2)\ V_{DC}}{(\sqrt{2}/2)\ I_M\ (1.11\ V_{DC})} = 0.812.$$

The bridge rectifier circuit has the same utilization factor as the primary of the full-wave center-tap circuit. The UF of the single-phase bridge is quite high and is only exceeded by certain polyphase circuits.

The reciprocal of UF is usually indicated in tables such as Table 1, because circuit descriptions are generally normalized to the dc output current or voltage. However, utilization factor does not tell the whole story in the case of a half-wave circuit since only one half of the sine wave of current is passed, and the windings carry a dc component of current which magnetizes the iron core and increases the core losses. As a result, half-wave rectifiers are only practical for use with a transformer when the current requirement is very small.

RIPPLE FACTOR

The rectified voltage and current output consists of a series of unidirectional waves or ripples. For some applications these variations are not objectionable but for others they must be smoothed out by filters. For all cases the relative magnitude of the ripple is important in the comparison of rectifying circuits. The comparison is made in terms of ripple factor. Ripple factor is the ratio of effective value of the alternating components of the rectified voltage or current to the average value. In equation form ripple factor is

$$r_f = \frac{\text{effective rectified ac load component } (I_{RMS})}{\text{average load current } (I_{DC})}. \qquad (7)$$

Percent ripple is a term used interchangeably with ripple factor and is simply the ripple factor expressed in percent ($r_f \times 100$).

The various components of current associated with ripple factor are illustrated in Figure 3. Part (a) shows the single current pulse of half-wave rectification, and part (b) shows the splitting of the pulse into a dc component and a ripple component. Parts (c) and (d) give an actual separation of the components, and part (e) illustrates the components for full-wave rectification.

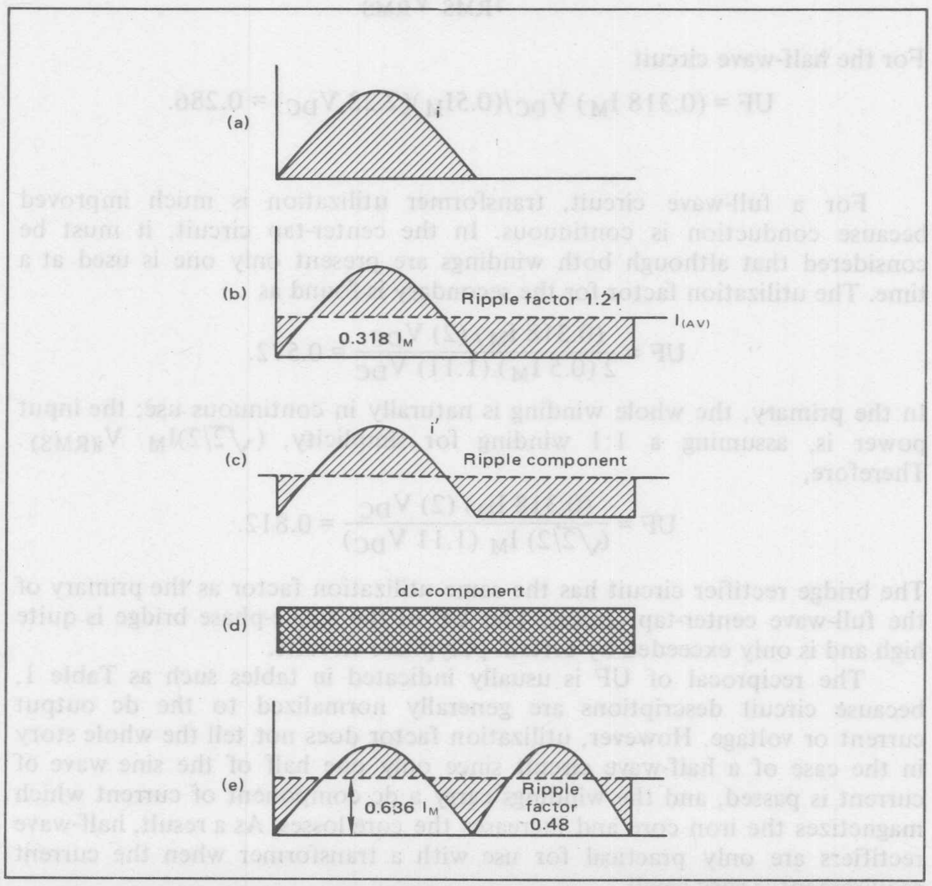


Figure 3 – Illustration of ripple factors for half-wave and full-wave circuits

component shown in part d. This ratio may be computed by following the preceding form of calculation. Thus the instananeous ac ripple component i′ may be represented as

$$i' = i - I_{DC}, \tag{8}$$

and the total rms value of the ripple component I'_{rms} is

$$I'_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (i \quad I_{DC})^2 \, d\theta} \tag{9}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} (i^2 - 2I_{DC}\, i + I_{DC}^2)\, d\theta.}$$

The first term in this expression is the rms value of the total current $I_{(RMS)}$. The integral of the $id\theta$ part of the second term integrates to the average value $I_{(DC)}$, and the last term is simply $I^2{}_{DC}$ after the limits are applied. Thus

$$I'_{rms} = \sqrt{I_{RMS}^2 - 2I_{DC}^2 + I_{DC}^2}$$

After algebraic manipulation and substituting the form factor F for I_{RMS}/I_{DC}, in Equation 7, the ripple factor is

$$r_f = \sqrt{F^2 - 1.} \tag{10}$$

(F is the form factor of the output current, not the diode current.) Substitution of values from Figures 1 and 2 into Equation 10 gives

$$\text{Half-wave } F = \frac{0.5\, I_M}{0.318\, I_M} = 1.57$$

$$r_f = \sqrt{1.57^2 - 1} = 1.21.$$

$$\text{Full-wave } F = \frac{0.707\, I_M}{0.636\, I_M} = 1.11$$

$$r_f = \sqrt{1.11^2 - 1} = 0.482.$$

RECTIFICATION RATIOS (CONVERSION EFFICIENCY)

The preceding discussion of ripple factor leads to the idea that the heating losses (I^2R) which occur in the various parts of the complete rectifier circuit are increased by the irregular waveforms of current that are inherent in the rectifying process. (This loss may be illustrated by comparing the heating loss caused by a smooth or filtered direct current to that resulting from the actual current waves of Figure 3, parts a, b, and c.) The resulting ratio may be termed the ratio of rectification, σ, and is written as

$$\sigma = \frac{I_{(DC)}^2 \, R_L}{I_{(RMS)}^2 \, R_L}. \tag{11}$$

Substitution of the appropriate current values in terms of I_M yields:

$$\sigma = .406 \text{ (half-wave)},$$

$$\sigma = .812 \text{ (full-wave)}.$$

The ratio of Equation 11 is sometimes called the conversion efficiency. The latter terminology is somewhat misleading since the overall power efficiency for the assumed conditions (zero losses) must be 100 percent. The real significance of the ratio of rectification is that it gives a qualitative indication of the increased heat losses that occur wherever a pulsating current flows through resistance elements. A second method of expressing the increased heat losses is by the current form factor, discussed earlier, which is the ratio of the root-mean-square to the average value.

VOLTAGE RELATIONSHIPS

The input voltage required to achieve a given dc output voltage (V_{DC}) is a necessary piece of design information. The output voltage (V_{DC}) is I_{DC} R_L and Equation 2 states that $I_{DC} = 0.318\ I_M$ for the half-wave circuit. The peak current (I_M) is V_M/R_L and the rms input voltage $V_i = V_M/\sqrt{2}$. Combining these relationships yields:

$$V_{DC} = (.318)(\sqrt{2})\ V_i. \tag{12}$$

The ratio of V_i to V_{DC} is 2.22 for the half-wave circuit. The ratio for a given input voltage per transformer leg is only half this value for the full-wave circuit which produces twice the dc level as the half-wave circuit.

Another voltage of importance is the maximum voltage which the rectifier must block when it is not conducting. It is called the peak inverse voltage, or in rectifier parlance, V_{RRM}. V_{RRM} is the sum of the peak input voltage and the rectifier peak output voltage at the same instant of time.

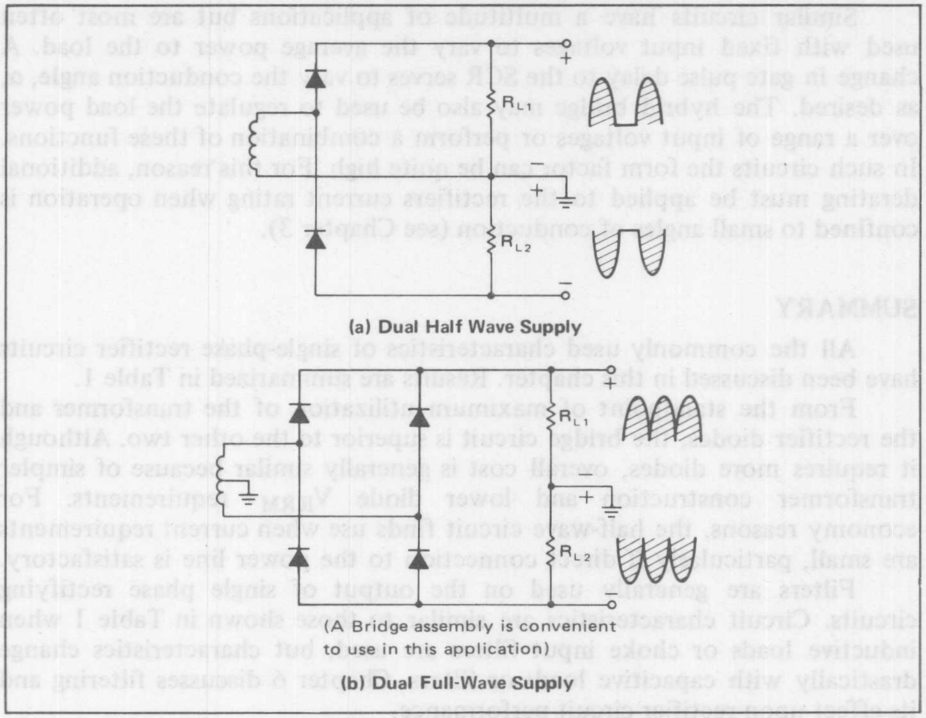
In the half-wave circuit of Figure 1, the output voltage is zero when the input voltage reaches its negative peak; therefore,

$$V_{RRM} = V_M = (\sqrt{2})(2.22\ V_{DC}) = 3.14\ V_{DC}.$$

In the full-wave center-tap circuit, the output voltage is maximum at V_M, because of rectifier conduction on one side, when the other side must block V_M. Therefore, $V_{RRM} = 2\ V_M$, but now the rms input voltage, V_M is 1.11 V_{DC}, making $V_{RRM} = (\sqrt{2})(2)(1.11)\ V_{DC} = 3.14\ V_{DC}$. For the bridge, the blocking rectifiers are across the output voltage; therefore, the maximum reverse voltage is V_M. Consequently, $V_{RRM} = (\sqrt{2})(1.11)\ V_{DC} = 1.57\ V_{DC}$. Low peak inverse voltage requirements are one of the principle advantages of bridge circuits.

CIRCUIT VARIATIONS

Many applications require equal positive and negative output voltages. The voltages may be obtained from voltage dividers if the loads are fixed. However, most supplies must handle variable loads and often rely on the basic circuits shown in Figure 4 to maintain dual output voltages. These circuits are simply combinations of the standard half-wave and center-tapped full-wave circuits previously discussed. Chapter 2 illustrates how a rectifier bridge assembly may be properly handled in the circuit of Figure 4b. If the



(a) Dual Half Wave Supply

(A Bridge assembly is convenient to use in this application)

(b) Dual Full-Wave Supply

Figure 4 – Single-Phase Supplies with dual output voltages

loads are similar, the circuit of Figure 4a does not have a poor transformer utilization factor, thereby overcoming one objection to the half-wave circuit.

The standard rectifier diode, being just a two terminal device, has no internal means of regulating current. It is often used, however, in conjunction with controllable rectifiers such as SCRs in circuits similar to the hybrid bridge rectifier shown in Figure 5.

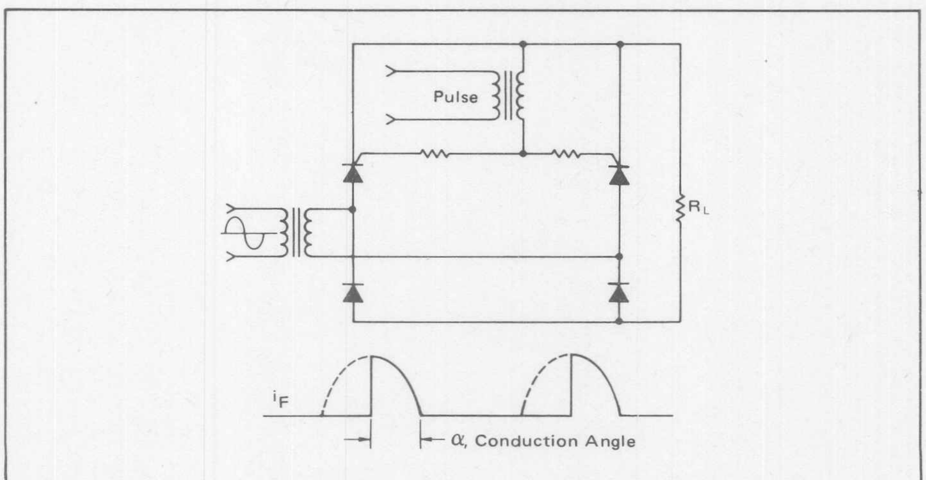


Figure 5 – Typical Hybrid Bridge Rectifier with Resulting Diode Current Waveform

Similar circuits have a multitude of applications but are most often used with fixed input voltages to vary the average power to the load. A change in gate pulse delay to the SCR serves to vary the conduction angle, α, as desired. The hybrid bridge may also be used to regulate the load power over a range of input voltages or perform a combination of these functions. In such circuits the form factor can be quite high. For this reason, additional derating must be applied to the rectifiers current rating when operation is confined to small angles of conduction (see Chapter 3).

SUMMARY

All the commonly used characteristics of single-phase rectifier circuits have been discussed in this chapter. Results are summarized in Table 1.

From the standpoint of maximum utilization of the transformer and the rectifier diodes, the bridge circuit is superior to the other two. Although it requires more diodes, overall cost is generally similar because of simpler transformer construction and lower diode V_{RRM} requirements. For economy reasons, the half-wave circuit finds use when current requirements are small, particularly if direct connection to the power line is satisfactory.

Filters are generally used on the output of single phase rectifying circuits. Circuit characteristics are similar to those shown in Table 1 when inductive loads or choke input filters are used, but characteristics change drastically with capacitive loads or filters. Chapter 6 discusses filtering and its effect upon rectifier circuit performance.

CHAPTER 5: POLYPHASE RECTIFIER CIRCUITS

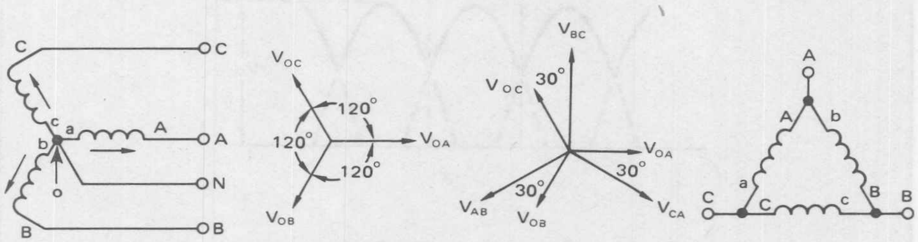
Polyphase rectifiers are generally preferred where the dc power required is in the order of 1 kW or more. Compared with single-phase circuits, the polyphase rectifiers develop an output voltage wave into a resistive load that is much closer to a steady dc potential than is the output of single-phase arrangements. Also, the more desirable of the various polyphase circuits give a higher output voltage in proportion to the peak inverse voltage and utilize the possibilities of the transformer more effectively than do the single-phase circuits. In polyphase applications, the primary windings of the transformers are often connected in a delta configuration with the secondary windings connected as either a wye or delta configuration, or both. While the primary source of power is distributed as a three-phase system, phase transformation with transformers can yield six or more phases with resultant improvements in rectifier performance. A multiplicity of polyphase circuits have been devised; only a few are of relative importance. The intent of this chapter is to develop some of the basic relationships to show the demands placed upon the rectifier diode by some of the more popularly used circuits. More exhaustive studies are found in the references.

REVIEW OF POLYPHASE BASICS

All significant amounts of electrical power are handled by three-phase distribution systems because:

1. Less copper is required to supply a given load power with a polyphase system than with a single-phase system of the same voltage.
2. If the load on each phase is identical, the instantaneous power demanded from the source is constant, i.e., it does not have the $\sin^2$ variations of a single-phase source.
3. Coils may be connected to a polyphase source such that a magnetic field is developed which has a constant flux density and rotates at the frequency of the applied sine wave, a feature which simplifies ac motor construction.

Transformer windings may be wye (Y) or delta (Δ) connected. When Y connected as in Figure 1a, voltages from any terminal (i.e., A, B, or C) to the



(a) Wye-connected Transformer windings (b) Phase Voltage Relationships (c) Complete Voltage Vector (d) Delta-connected Transformer windings

Figure 1 — Y and Δ Connections and Appropriate Phase Relationships

neutral (N) are called phase voltages and appear on a vector diagram as shown in Figure 1b. The voltages V_{AB}, V_{BC}, and V_{CA} are called line voltages. The line voltages are also 120° out of phase, but because they are the vector sum of two phase voltages they are $\sqrt{3}$ times larger and are displaced 30° from the phase voltages as shown in part (c). A common method of transformer connection in the delta connection indicated by part (d) The voltage across the delta terminal is the same as the line voltage, and consequently bears the same relationship to the phase voltage as the line voltage.

When a three-phase system is driving a balanced load, the power is given by

$$P = \sqrt{3}\, V\, I, \tag{1}$$

where P = total power,

V = rms phase or line voltage,

I = corresponding rms phase or line current.

By summing voltages from two phases in a transformer, a voltage bearing any desired amplitude and phase shift from a phase voltage may be obtained. Thus, there is no inherent limit to the number of phases which may be generated.

GENERAL RELATIONSHIPS IN POLYPHASE RECTIFIERS

The analysis of polyphase rectifier circuits may be greatly simplified if the transformers and rectifiers are idealized; that is, they are assumed to possess no resistance or leakage reactance. Furthermore, the diode is assumed to have a zero forward voltage drop and a zero reverse current. By idealizing the components, simple general expressions can be derived for polyphase rectifiers.

Figure 2 shows the rectified voltage waveform for the general case of a

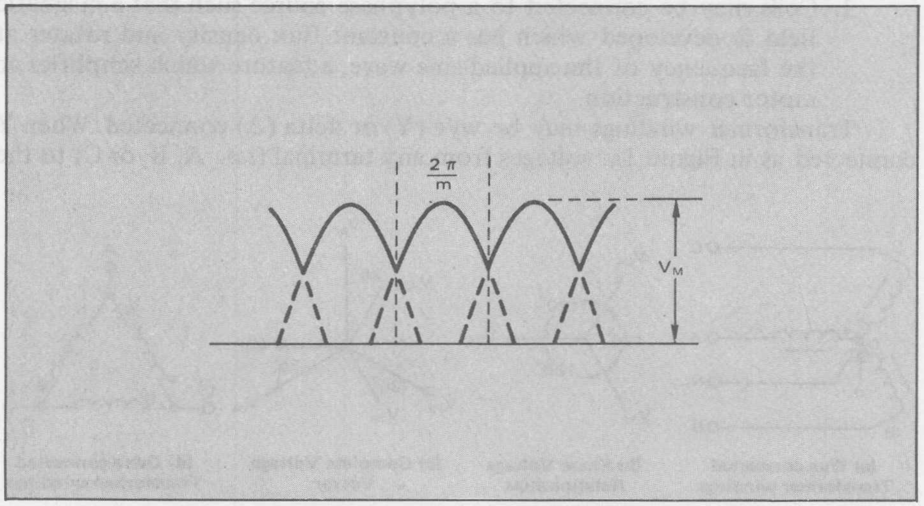


Figure 2 — Rectified Voltage Waveform For Multiphase Rectifier Circuit m is the number of output pulses per cycle

polyphase rectifier circuit with a resistive load (See Figure 3 for the simplest polyphase rectifier circuit). Conduction takes place through the rectifier with the highest voltage across it. Note that neither the voltage nor the current is ever zero in the load. The instantaneous load voltage of Figure 2 is equal to the voltage of the conducting phase, and is given by

$$v_L = V_M \sin\theta, \tag{2}$$

where V_M = the peak phase-to-neutral voltage.

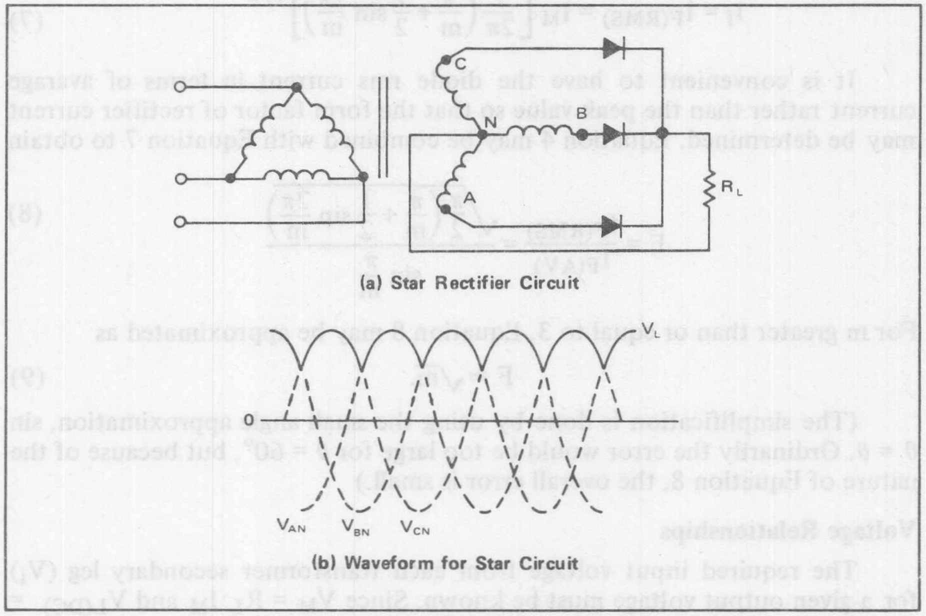


Figure 3 – Circuit and Waveforms for the Three-Phase Star or Half-Wave Rectifier Circuit

Current Relationships

As with single-phase circuits, the average value of output current or dc value is of prime interest. It is the average value of the instantaneous rectified current over one cycle or a period of $2\pi/m$ radians (See Figure 2). Using the integral calculus, the average current per phase equals the rectifier diode current and is given by

$$I_{F(AV)} = \frac{I_M}{2\pi} \int_{(\pi/2)+(\pi/m)}^{(\pi/2)+(\pi/m)} \sin\theta \, d\theta. \tag{3}$$

Solving,

$$I_{F(AV)} = \frac{I_M}{\pi} \left[\sin\left(\frac{\pi}{m}\right) \right]. \tag{4}$$

The total load current (I_L) is m times the current per conducting phase or

$$I_{L(DC)} = I_M \left(\frac{m}{\pi} \sin\frac{\pi}{m} \right). \tag{5}$$

The rms current (I_f) is also of interest as it determines heating in the transformer winding resistance and in the diode. The rms value varies as the square of the instantaneous current and may be obtained by integration.

$$I_f = I_{F(RMS)} = \left[\frac{1}{2\pi} \int_{(\pi/2)-(\pi/m)}^{(\pi/2)+(\pi/m)} I_M^2 \sin^2\theta \, d\theta \right]^{1/2} \tag{6}$$

$$I_f = I_{F(RMS)} = I_M \left[\frac{1}{2\pi} \left(\frac{\pi}{m} + \frac{1}{2} \sin \frac{2\pi}{m} \right) \right]^{1/2} \tag{7}$$

It is convenient to have the diode rms current in terms of average current rather than the peak value so that the form factor of rectifier current may be determined. Equation 4 may be combined with Equation 7 to obtain

$$F = \frac{I_{F(RMS)}}{I_{F(AV)}} = \frac{\sqrt{\frac{\pi}{2}\left(\frac{\pi}{m} + \frac{1}{2} \sin \frac{2\pi}{m} \right)}}{\sin \frac{\pi}{m}} \tag{8}$$

For m greater than or equal to 3, Equation 8 may be approximated as

$$F \approx \sqrt{m}. \tag{9}$$

(The simplification is done by using the small angle approximation, sin $\theta = \theta$. Ordinarily the error would be too large for $\theta = 60°$, but because of the nature of Equation 8, the overall error is small.)

Voltage Relationships

The required input voltage from each transformer secondary leg (V_i) for a given output voltage must be known. Since $V_M = R_L I_M$ and $V_{L(DC)} = R_L I_{L(DC)}$, substituting these relationships into Equation 5 results in

$$V_{L(DC)} = V_M \left(\frac{m}{\pi} \sin \frac{\pi}{m} \right) \tag{10}$$

The rms value of V_i is $V_M \sqrt{2}/2$ from which

$$V_i = \frac{V_{L(DC)}}{\sqrt{2}\left(\frac{m}{\pi} \sin \frac{\pi}{m} \right)} \tag{11}$$

The peak repetitive reverse voltage or peak inverse voltage applied to the rectifier, V_{RRM}, is also of vital interest. In full-wave center-tapped circuits, it is the sum of the load and peak input voltage at the same instant of time.

To obtain exact values, the precise output waveform must be considered. However, V_{RRM} cannot exceed 2 V_M and in many polyphase circuits $V_{L(DC)} \approx V_M$. To be conservative, let $V_L = V_M$; since $V_{i(PK)} = V_L \sqrt{2}$, using Equation 11 above, V_{RRM} can be put in terms of voltage as

$$V_{RRM} \leqslant 2 \left(\frac{V_{L(DC)}}{\frac{m}{\pi} \sin \frac{\pi}{m}} \right) \tag{12}$$

For bridge connections, V_{RRM} is just the peak output voltage, which is one half of that given by Equation 12.

Transformer Utilization

High transformer utilization is one of the chief benefits of polyphase rectifier systems. The utilization factor, (UF), discussed in Chapter 4, is the ratio of dc power in the load to the volt ampere or power rating of the transformer and is commonly used in comparing rectifier circuits. As defined,

$$UF = \frac{I_{(AV)}\ V_{(AV)(OUTPUT)}}{I_{(RMS)}\ V_{(RMS)(INPUT)}} \qquad (13)$$

Values for the terms depend upon whether primary or secondary UF is desired. The utilization factor of the primary is found by considering the total volt-ampere requirement of the transformer and the total dc load power. The secondary utilization factor generally considers only a particular winding's contribution to the load and the volt-ampere requirement of the winding.

Utilization factors can only be computed by studying the voltage and current relationships in a particular circuit configuration. It can be shown(1) that the highest utilization factor occurs when m = 3, i.e., conduction occurs in a winding for 120°. In this case, the winding is idle for two-thirds of the cycle. The larger the number of phases, the longer is the idle time and the less effectively is the transformer being used. To achieve high utilization factors and also the advantages of 6 or 12 phase operation, bridge circuits are used and special secondary winding arrangements have been devised, which permit m to be 3 for the secondary windings; however, m is effectively 6 or 12 for the output voltage waveform.

Ripple

The same relationship for ripple holds true for polyphase circuits as with single phase circuits, i.e.,

$$r_f = \sqrt{\frac{I_{L(RMS)}}{I_{L(DC)}} - 1} \qquad (14)$$

An expression for the various ripple harmonics is obtained for the general polyphase rectifier system by applying Fourier analysis to the waveform. The resulting expression is given by

$$r_f = \frac{V_{mn}}{\sqrt{2}\ V_{L(DC)}} = \frac{\sqrt{2}}{(nm)^2 - 1} \qquad (15)$$

where r_f = the ripple factor due to the n^{th} harmonic,

V_{mn} = the peak voltage of the n^{th} harmonic,

$V_{L(DC)}$ = the dc output voltage,

m = the number of output pulses per cycle,

n = the order of the harmonic.

In Equation 15, the only harmonics involved are multiples of m. Thus, for m = 3, only the third, sixth, ninth, etc., harmonics of the input voltage contribute to the ripple voltage.

Rectification Ratio

The last general item of interest is the rectification ratio, σ, sometimes referred to as waveform or conversion efficiency. It is the ratio of dc power in the load ($I^2_{L(DC)}\ R_L$) to rms power in the load ($I^2_{L(RMS)}\ R_L$). Since the load resistance cancels in the ratio and $I_{L(RMS)}/I_{L(DC)}$ is the load current form factor, the rectification ratio is

$$\sigma = \frac{1}{[F\,(\text{load})]^2} \tag{16}$$

To find the rectification ratio, the total rms component of load current must be known. It may be found from Equation 6 by recognizing that the total current will be m times the phase current. Therefore,

$$I_{L(RMS)} = \left[\frac{m}{2\pi}\int_{(\pi/2)-(\pi/m)}^{(\pi/2)+(\pi/m)} I^2_M \sin^2\theta \, d\theta\right]^{1/2} \tag{17}$$

Solving,

$$I_{L(RMS)} = I_M\left[\frac{m}{2}\left(\frac{\pi}{m} + \frac{1}{2}\sin\frac{2\pi}{m}\right)\right]^{1/2} \tag{18}$$

By comparing Equation 18 to Equation 7, it can be seen that rms load current is simply $\sqrt{m}$ times rectifier leg current and the load current is m times the rectifier leg current. Therefore, the form factor of the load is simply $1/\sqrt{m}$ times the rectifier leg form factor as given by Equation 8. Accordingly:

$$F\,(\text{load}) = \frac{\sqrt{\dfrac{\pi}{2m}\left[\dfrac{\pi}{m} + \dfrac{1}{2}\sin\dfrac{2\pi}{m}\right]}}{\sin \pi/m} \tag{19}$$

An attempt to simplify Equation 19 as done with Equation 8 yields unity. Therefore, it must be used without approximation to yield significant results. Substituting Equation 19 into Equation 16 yields:

$$\sigma = \frac{2m\sin^2(\pi/m)}{\left(\dfrac{\pi}{m} + \dfrac{1}{2}\sin\dfrac{2\pi}{m}\right)} \tag{20}$$

Other Factors

Leakage reactance in the transformer and diode reverse recovery time causes overlap, i.e., a period of time where current flows in two diodes, each in different branches, at one time. Overlap is caused because leakage inductance and the diodes will not allow current in the individual phases to change instantaneously. One effect of overlap is to reduce the output of the rectifier circuit. This reduction, along with the voltage drop in the rectifier and transformer should be calculated and used to correct the output voltage predicted ideally. The overlap problem is discussed more fully in Chapter 6 and in the references.

COMMON POLYPHASE RECTIFIER CIRCUITS

The remainder of this chapter is devoted to a discussion of the basic and more popular rectifier circuit configurations. Pertinent characteristics of each circuit are listed in Table 1.

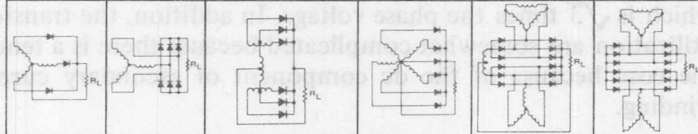
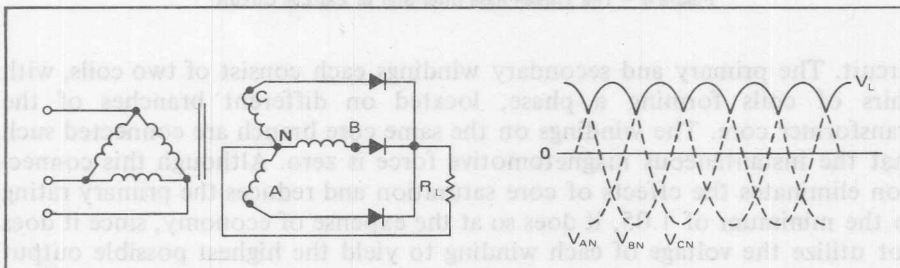
	HALF-WAVE STAR	BRIDGE	DOUBLE WYE WITH INTERPHASE TRANSFORMER	FULL-WAVE STAR	WYE-DELTA CONNECTIONS PARALLEL	WYE-DELTA CONNECTIONS SERIES
RECTIFIER CIRCUIT CONNECTION						
LOAD VOLTAGE and CURRENT WAVESHAPE						
CHARACTERISTIC						
Average Current Through Diode, $I_{F(AV)}/I_{L(DC)}$	0.333	0.333	0.167	0.167	0.167	0.333
Peak Current Through Diode, $I_{FM}/I_{F(AV)}$	3.63	3.14	3.15	6.30	6.30	6.30
Form Factor of Current Through Diode, $I_{F(RMS)}/I_{F(AV)}$	1.76	1.74	1.76	2.46	2.46	2.46
RMS Current Through Diode, $I_{F(RMS)}/I_{L(DC)}$	0.587	0.579	0.293	0.409	0.409	0.818
RMS Input Voltage Per Transformer Leg, $V_i/V_{L(DC)}$	0.855	0.428	0.855	0.741	0.715	0.37
Diode Peak Inverse Voltage (P.I.V.), $V_{RRM}/V_{L(DC)}$	2.09	1.05	2.42	2.09	1.05	1.05
Transformer Primary Rating, VA/P_{DC}	1.23	1.05	1.06	1.28	1.01	1.01
Transformer Secondary Rating, VA/P_{DC}	1.50	1.05	1.49	1.81	1.05	1.05
Total RMS Ripple, %	18.2	4.2	4.2	4.2	1.0	1.0
Lowest Ripple Frequency, f_r/f_i	3	6	6	6	12	12
Rectification Ratio (Conversion Efficiency), %	96.8	99.8	99.8	99.8	100	100

TABLE 1: SUMMARY OF SIGNIFICANT THREE PHASE RECTIFIER CIRCUIT CHARACTERISTICS FOR RESISTIVE LOADS. (See Table 1 Chapter 6 for Inductive Load Data)

Note: $P_{DC} = I^2_L R_L$, $V_L = I_L R_L$

Three-Phase Star Rectifier Circuit

The three-phase star rectifier circuit, often referred to as the three-phase half-wave rectifier, is illustrated in Figure 3a. The associated voltage waveforms are shown in Figure 3b. Because the circuit is economical, it finds



(a) Star Rectifier Circuit

(b) Waveform for Star Circuit

Figure 3 — Circuit and Waveforms for the Three-Phase Star or Half-Wave Rectifier Circuit

limited use where dc output voltage requirements are relatively low and current requirements are too large for practical single phase systems. The circuit is worth studying, however, because it is a building block of more complicated systems. By using the equations developed in the preceding section, the various items of interest may be calculated as given in Table 1.

The dc output voltage is approximately equal to the phase voltage. However, the diodes must block approximately the line-to-line voltage, which is $\sqrt{3}$ times the phase voltage. In addition, the transformer design and utilization are somewhat complicated because there is a tendency to saturate the core because of the dc component of secondary current flow in each winding.

Three-phase Inter-Star Rectifier Circuit

The three-phase inter-star or zig-zag rectifier circuit in Figure 4 overcomes some of the transformer limitations of the three-phase star

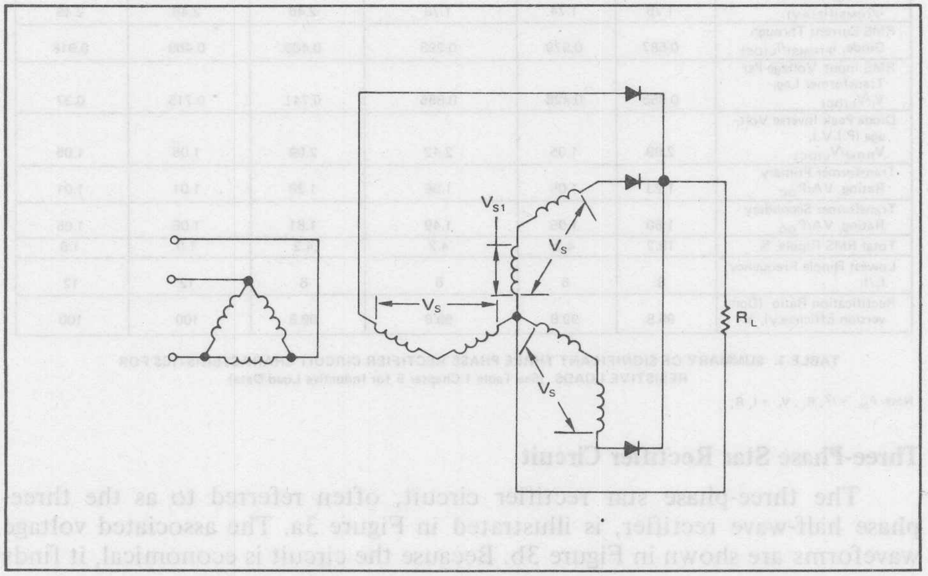
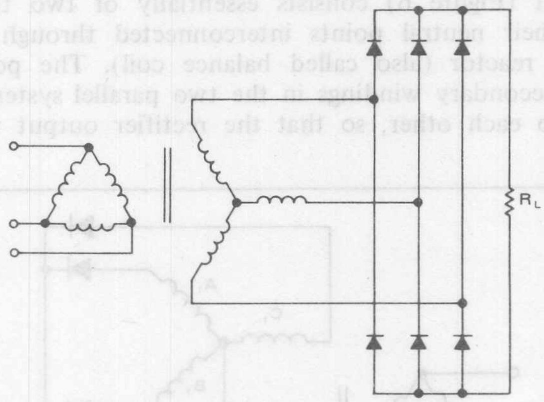


Figure 4 – The Three-Phase Inter-Star or Zig-Zag Circuit

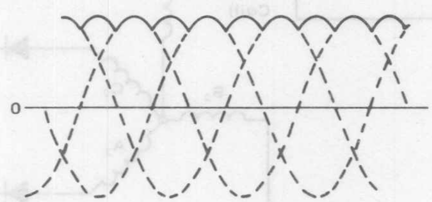
circuit. The primary and secondary windings each consist of two coils, with pairs of coils forming a phase, located on different branches of the transformer core. The windings on the same core branch are connected such that the instantaneous magnetomotive force is zero. Although this connection eliminates the effects of core saturation and reduces the primary rating to the minimum of 1.05, it does so at the expense of economy, since it does not utilize the voltage of each winding to yield the highest possible output voltage. The two secondary windings in series give a voltage of $\sqrt{3}V_{S1}$ instead of $2V_{S1}$. This results from the addition of two sinor voltages that are 60° apart. As a result, the secondary volt ampere rating must be increased from the 1.48 value shown in Table 1 to 1.71. Otherwise, circuit constants are the same as the three-phase star circuit, except for the required secondary voltage.

Three-Phase Full-Wave Bridge Circuit

A three-phase full-wave bridge connection is commonly used whenever high dc power is required, as it exhibits a number of excellent attributes. It has a low ripple factor, low diode PIV, and the highest possible transformer utilization factor for a three-phase system. Because of the full-wave rectification associated with each secondary winding, it is permissible to use any combination of wye or delta primary and secondary windings or three single-phase transformers in place of one three-phase transformer. A schematic of the circuit is shown in Figure 5a. The voltage waveforms are shown in Figure 5b.



(a) Three-Phase Full-Wave Bridge Circuit. The secondary may also be delta-connected; the primary may be wye-connected.



(b) Voltage Waveforms, Solid Line is Output Voltage and the Dashed Lines are the Phase Voltages.

Figure 5 — Three-Phase Full-Wave Bridge Circuit and Associated Waveforms

Each conduction path through the transformer and load passes through two rectifiers in series; a total of six rectifier elements are required. Commutation in the circuit takes place every 60°, or six times per cycle which reduces the ripple to 4.2% and increases the fundamental frequency of ripple to six times the input frequency. No additional filtering is required in most applications. Thus, with this circuit the low ripple factor of a six-phase system is achieved while still obtaining the high utilization factor of a three-phase system. The dc output voltage is approximately equal to the peak line voltage or 2.4 times the rms phase voltage; each diode must block

only the output voltage. Three-phase bridge connections are popular and are recommended wherever both dc voltage and current requirements are high.

The circuit characteristics are obtained by substituting m = 6 in the general equations. Results are shown in Table 1.

Three-Phase Double-Wye Rectifier with Interphase Transformer

The three-phase double-wye rectifier circuit is frequently used instead of a bridge circuit because each rectifier diode contributes only 1/6th instead of 1/3rd of the load current. However, the peak inverse voltage for this circuit is higher than the three-phase star system due to the interphase reactor.

The circuit (Figure 6) consists essentially of two three-phase star circuits with their neutral points interconnected through an interphase transformer or reactor (also called balance coil). The polarities of the corresponding secondary windings in the two parallel systems are reversed with respect to each other, so that the rectifier output voltage of one

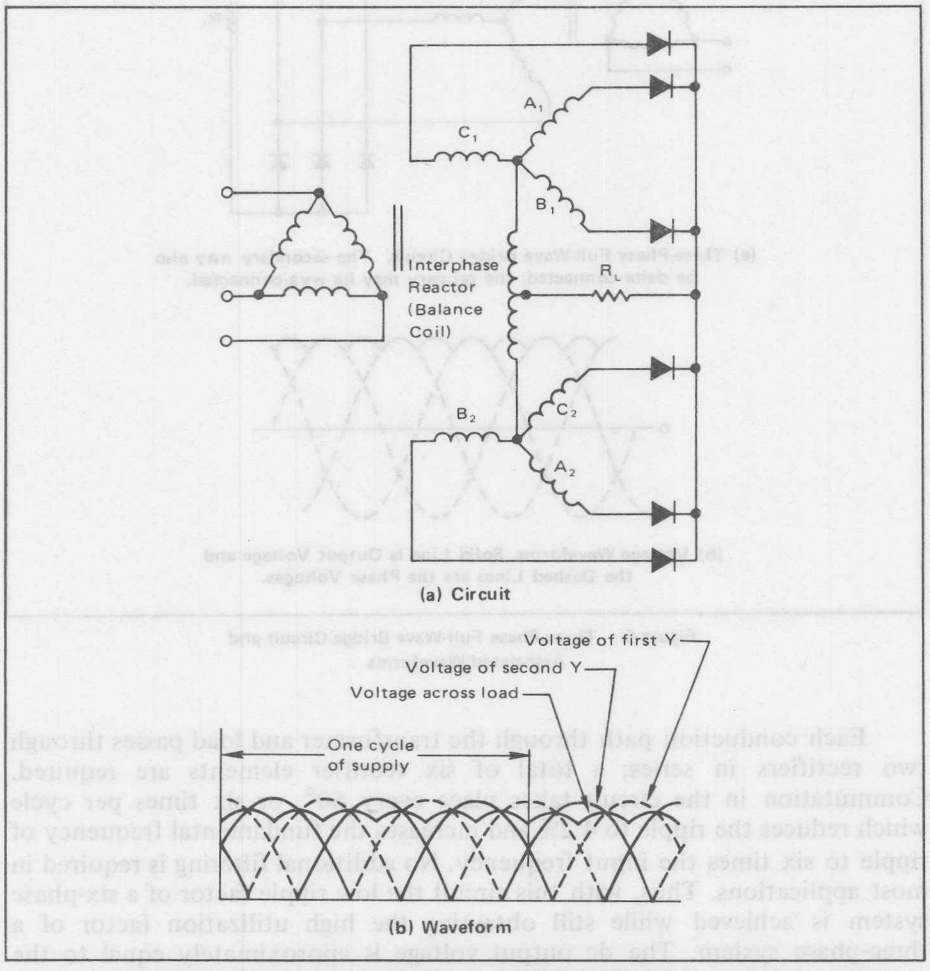


Figure 6 – Circuit and Waveforms for the Three-Phase Double Wye Circuit

three-phase unit is at a minimum when the rectifier output voltage of the other unit is at a maximum, as shown. The action of the balance coil is to cause the actual voltage at the output terminals to be the average of the rectified voltages developed by the individual three-phase systems. The output voltage of the combination is therefore more nearly constant than that of a three-phase half-wave system; moreover, the ripple frequency of the output wave is now six times that of the supply frequency, instead of three times.

In order that the individual three-phase half-wave systems may operate independently with current flowing through each diode one third of the time, the interphase reactor must have sufficient inductance so that the alternating current flowing in it as a result of the voltage existing across the coil has a peak value less than one half the dc load current. That is, the peak alternating current in the interphase reactor must be less than the direct current flowing through one leg of the coil. Since the direct current flows in opposite directions in the two halves of the interphase reactor, no dc saturation is present in this reactor.

Six-Phase Star Rectifier Circuit

The six-phase star rectifier circuit is often referred to as the three-phase diametric or full-wave rectifying circuit because it has a center-tapped transformer. The six-phase star circuit is shown in Figure 7. The characteristics are obtained from the general rectifier equations where m is equal to six. Fields of application include requirements for very high dc load currents in low-to-medium voltage ranges. Voltage is usually restricted because the peak inverse voltage applied to the diodes is twice the peak phase voltage and transformer secondary utilization is poor. Current flows in only one rectifying element at a time, resulting in a low average current, but a high peak to average current ratio in the diodes.

The six-phase star circuit is attractive in applications which require a low ripple factor and a common cathode or anode connection for the rectifiers. The primary winding is generally delta-connected, although a wye connection is sometimes used with a tertiary winding. An additional advantage of the six-phase star is that the dc currents cancel in the secondary, and therefore, the tendency toward core saturation is eliminated.

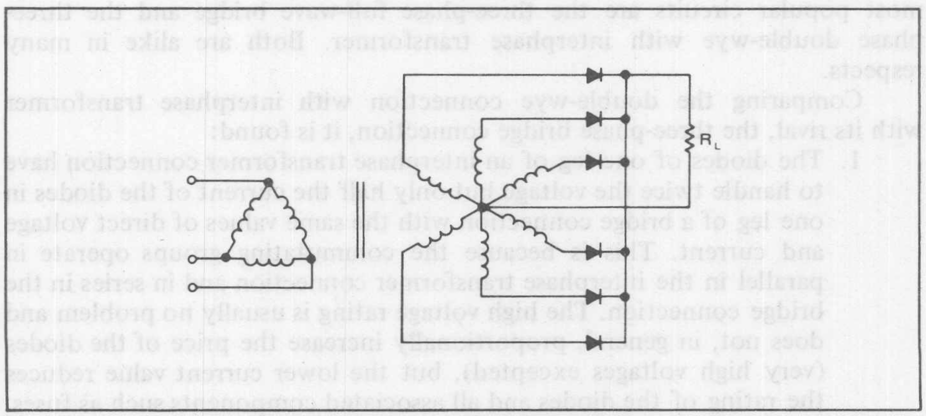


Figure 7 — The Six-Phase Star Circuit

Six-Phase Full-Wave Bridge Circuits

In many applications, it is necessary to reduce ripple below the 4.2% level characteristic of three-phase, full-wave and six-phase, half-wave connections. A reduction to approximatedly 1.0% at a ripple frequency twelve times the input frequency can be achieved by using wye-delta secondaries which result in 30° phase shift between windings. Either parallel or series bridge connections may be used for the output as shown in Figure 8.

When an equalizing reactor is used to couple the two bridge sections as in part (a) the system behaves as two parallel three-phase bridge circuits, with each section supplying one-half the load current. The parallel connection of the two groups is preferable to avoid having current pass through four diodes in series, but for high-voltage applications, the series connection (as in part b) may result in a more economical design.

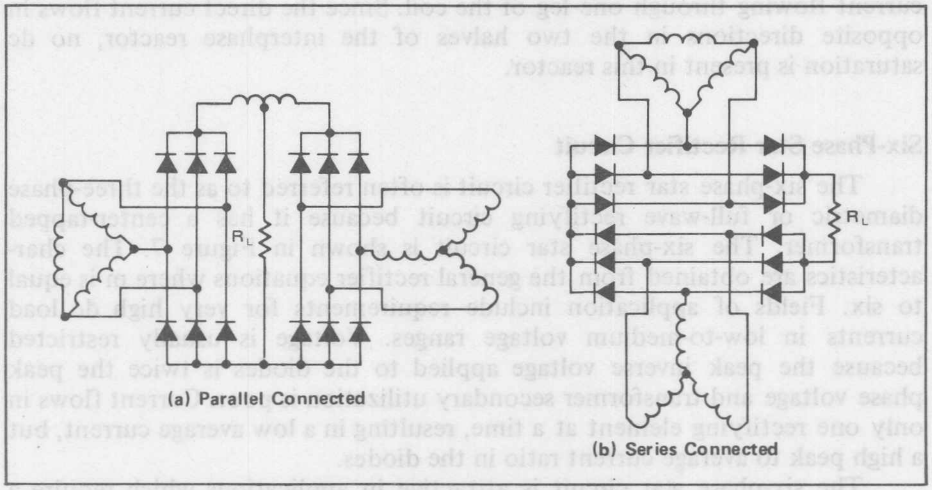


Figure 8 — Six-Phase Full-Wave Bridge Circuits

COMPARISON OF CIRCUITS

As mentioned previously, the three-phase and six-phase star circuits have limited application because of a number of disadvantages. By far, the most popular circuits are the three-phase full-wave bridge and the three-phase double-wye with interphase transformer. Both are alike in many respects.

Comparing the double-wye connection with interphase transformer with its rival, the three-phase bridge connection, it is found:

1. The diodes of one leg of an interphase transformer connection have to handle twice the voltage but only half the current of the diodes in one leg of a bridge connection with the same values of direct voltage and current. This is because the commutating groups operate in parallel in the interphase transformer connection and in series in the bridge connection. The high voltage rating is usually no problem and does not, in general, proportionally increase the price of the diodes (very high voltages excepted), but the lower current value reduces the rating of the diodes and all associated components such as fuses, bus bars and cooling equipment, and is therefore a great advantage.

2. The total power losses are smaller in an interphase transformer connection because of the lower current carried by the diodes.
3. The reactive voltage drop caused by the bus bars can be made smaller in an interphase transformer connection since the current to be commutated is only half of the current commutated in a bridge connection, and the commutating voltage is twice as high.

For these reasons the interphase transformer connection is competitive with the three-phase bridge connection in a certain voltage-current range, despite the relatively high transformer rating and the problem of avoiding saturation of the interphase transformer core due to current unbalance.

In special cases where low ripple is required and large power must be handled, a six-phase bridge or other high order system may prove attractive. Other useful systems are covered in the literature.(2)

References

1. Jacob Millman and Samuel Seely, *Electronics,* Chapter 14, second edition, McGraw-Hill Book Company, Inc., New York, New York, 1951.
2. Johannes Schaefer, *Rectifier Circuits: Theory and Design,* John Wiley and Sons, Inc., New York, New York, 1965.

CHAPTER 6: RECTIFIER FILTER SYSTEMS

Rectifiers without output filters, especially single-phase circuits, find limited application owing to their high ripple and relatively low conversion efficiency. Since the ultimate purpose of rectification is to produce a steady dc output voltage or current, the pulsating current from the rectifier(s) must be smooth. A Fourier analysis of the rectifier output waveform yields a series containing a constant term (the dc voltage) and a series of harmonic terms. The purpose of a filter is to extract the constant term and attenuate all harmonic terms. Since the input impedance of the filter influences the current and voltage relations of the transformer-rectifier combination, filters are broadly classified by the type of input-impedance element used. Naturally resistive filters consume power and hence are practical only in low-current, low-power applications. Capacitor-and inductor-input filters are widely used, the latter being almost mandatory in higher-power applications in order to avoid excessive turn-on and repetitive surge currents. Choke-input filters offer greatly reduced electro-magnetic interference, which is frequently caused by rectifier repetitive surge currents. More efficient transformer operation will also be obtained because of the reduction in form factor of the rectifier current. Unfortunately, chokes are bulky and expensive. If capacitor-input filters must be used, diodes whose average rating more nearly matches the load requirement can be used if a source to load resistance ratio of about 0.03 and voltage regulation of about 10 percent are acceptable.

Whereas a capacitor filter operates by attempting to hold the rectifier output voltage constant, an inductor attempts to hold the load current constant. The capacitor is thus more effective at light loads, the inductor at heavy loads or small values of the load resistance. Use of an inductor alone is generally impractical, particularly when variable loads must be handled because the attenuation is not sufficient with reasonable values of inductance. Analysis of a single L-R network shows that the ripple is reduced by the factor

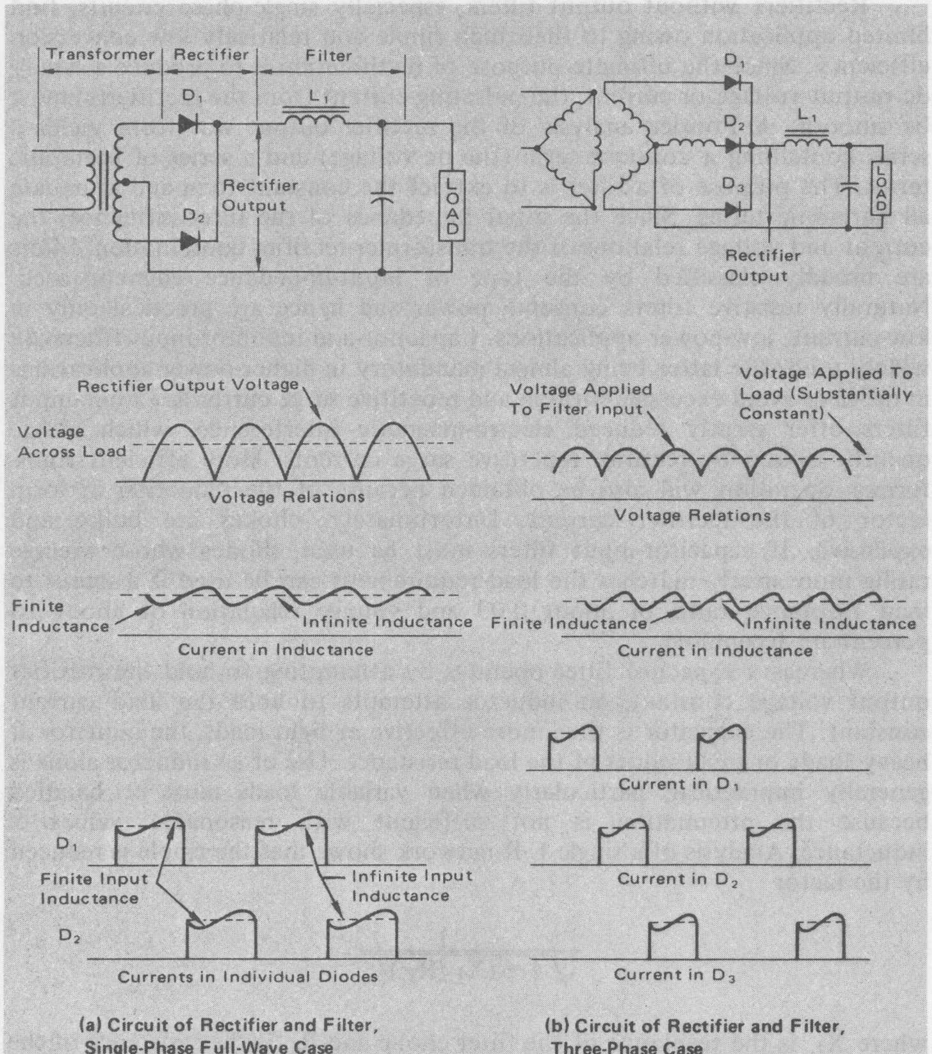
$$\frac{1}{\sqrt{1 + (X_L/R_L)^2}},$$

where X_L is the reactance of the filter choke and R_L is the resistance of the load. Unless $X_L \gg R_L$, filter action is ineffective. The basic inductor-input filter is therefore an L section employing both inductance and capacitance so that the complementary characteristics of the filter elements are used to advantage. It should also be noted that inductive loads, or filters, are not good practice in half-wave single-phase rectifiers owing to the large rectifier inverse-voltage transient which occurs when conduction inevitably ceases.

In the sections to follow, the influence of the filter upon rectifier circuit behavior and appropriate design procedures will be discussed, particularly as pertaining to the rectifier diode.

BEHAVIOR OF RECTIFIERS WITH CHOKE-INPUT FILTERS

The voltage and current relations existing in rectifier systems having series-inductance or choke-input filter are illustrated by the sketches of Figures 1 and 2. While these apply to specific rectifier circuits, the same general behavior occurs in all rectifier systems of the choke-input type.



These idealized waveforms are determined by assuming that the transformer leakage inductance is zero.
The effect of leakage inductance is considered in connection with Figure 3.

Figure 1 — Voltage and current waveforms existing in rectifier systems operating with choke-input filters

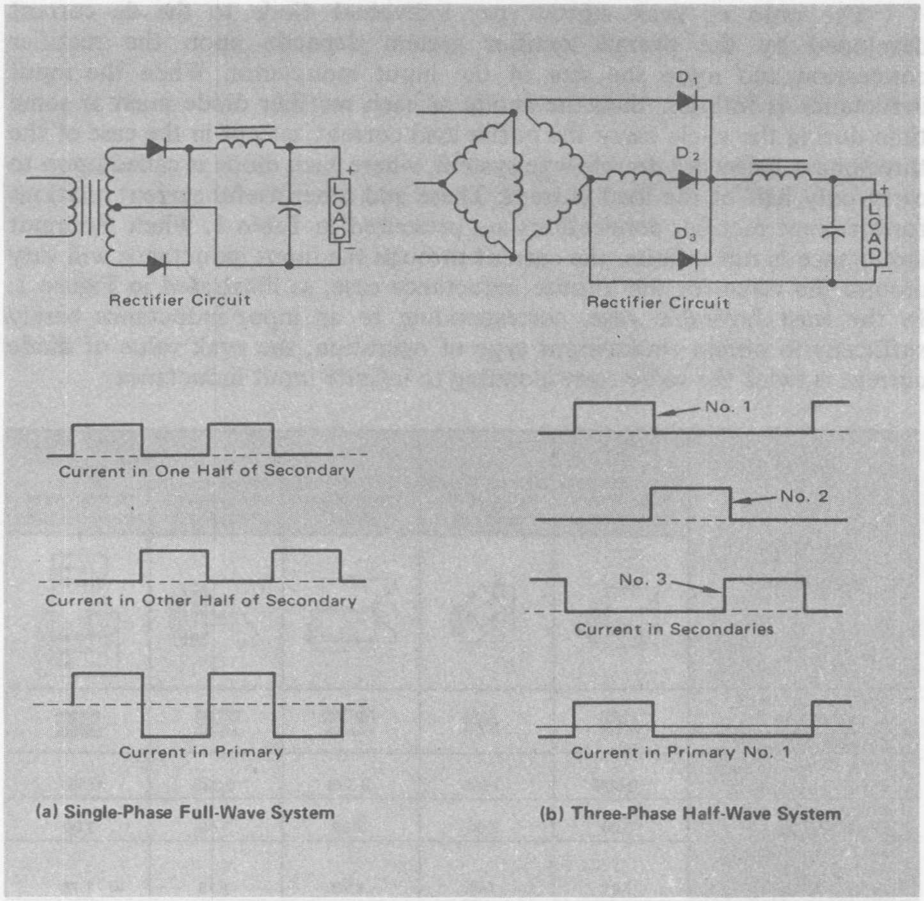
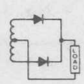
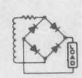
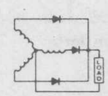
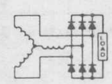
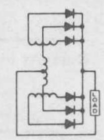
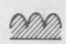


Figure 2 — Typical current waves in primary and secondary windings of transformer for ideal choke-input systems.

When the input inductance is infinite, the current through the inductance is constant and is carried at any moment by the rectifier diode that has a positive voltage (or the most positive voltage) applied to its anode at that instant. As the alternating voltage being rectified passes through zero (or when another anode becomes most positive), the current suddenly transfers from one diode to another, giving square current waves through the individual rectifier diodes, as shown by the dotted lines in Figure 1. When the input inductance is finite and not too small, the situation is as shown by the solid lines. The current through the input choke then tends to increase when the output voltage of the rectifier exceeds the average or dc value and to decrease when the rectifier output voltage is less than the dc value. This causes the current through the individual diodes to be modified as shown. If the input inductance is too small, the current decreases to zero during a portion of the time between the peaks of the rectifier output voltage, and the conditions then correspond to a capacitor-input filter system, as discussed later in this chapter.

The ratio of peak current per individual diode to the dc current developed by the overall rectifier system depends upon the rectifier connection and upon the size of the input inductance. When the input inductance is infinite, then the anode of each rectifier diode must at some time during the cycle carry the entire load current, except in the case of the three-phase half-wave double-wye system, where each diode is called upon to carry only half of the load current. These and other useful current relations for different rectifier connections are presented in Table 1. When the input inductance is not infinite, the current through the input inductance will vary around the value for the infinite inductance case, as illustrated in Figure 1. In the least favorable case, corresponding to an input inductance barely sufficient to obtain choke-input type of operation, the peak value of diode current is twice the value corresponding to infinite input inductance.

RECTIFIER CIRCUIT CONNECTION	SINGLE-PHASE FULL-WAVE CENTER-TAP	SINGLE-PHASE FULL-WAVE BRIDGE	THREE-PHASE HALF-WAVE STAR	THREE-PHASE FULL-WAVE BRIDGE	THREE-PHASE DOUBLE WYE WITH INTERPHASE TRANSFORMER
					
LOAD VOLTAGE WAVESHAPE					
CHARACTERISTIC					
‡Average Current Through Diode $I_{F(AV)}/I_{L(DC)}$	0.500	0.500	0.333	0.333	0.167
‡Peak Current Through Diode $I_{FM}/I_{F(AV)}$	2.00	2.00	3.00	3.00	3.00
Form Factor of Current Through Diode $I_{F(RMS)}/I_{F(AV)}$	1.41	1.41	1.73	1.73	→ 1.76
RMS Input Voltage Per Transformer Leg $V_i/V_{L(DC)}$	1.11*	1.11	0.855	0.428	0.855
Diode Peak Inverse Voltage (P.I.V.) $V_{RRM}/V_{L(DC)}$	3.14	1.57	2.09	1.05	42
Transformer Primary Rating VA/P_{DC}	1.11	1.11	1.21	1.05	1.05
Transformer Secondary Rating VA/P_{DC}	1.57	1.11	1.48	1.05	1.48
Ripple $(V_r/V_{L(DC)})$ Lowest frequency in rectifier output (f_r/f_i)	2	2	3	6	6
Peak Value of Ripple Components:					
Ripple frequency (fundamental)	0.667	0.667	0.250	0.057	0.057†
Second harmonic	0.133	0.133	0.057	0.014	0.014
Third harmonic	0.057	0.057	0.025	0.006	0.006
Ripple peaks with reference to d c axis:					
Positive peak	0.363	0.363	0.209	0.0472	0.0472
Negative peak	0.637	0.637	0.395	0.0930	0.0930

This table assumes that the input inductance is sufficiently large to maintain the output current of the rectifier substantially constant, and neglects the effects of voltage drop in the rectifier and the transformers. $P_{DC} = I^2_L R_L$, $V_L = I_L R_L$

*Secondary voltage on one side of center-tap.

†The principal component of voltage across the balance coil has a frequency of 3 fi and a peak amplitude of 0.500. The peak balance coil voltage, including the smaller, higher harmonics, is 0.605.

‡ Assumes infinite input inductance.

Table 1: Characteristics of Typical Rectifiers Operated with Inductance-Input Filter Systems

The voltage that the rectifier system applies to the input of a filter having a choke input can for nearly all practical purposes be considered as being given by the idealized curves showing the shape of the output voltage produced by an ideal rectifier system across a resistance load.

The output voltage wave of the rectifier can be considered as consisting of a dc component upon which are superimposed ac voltages, termed ripple voltages. In the case of the idealized full-wave single-phase rectifier, Fourier analysis shows that the output wave v_L has the equation*

$$v_L = \frac{2V_M}{\pi}\left(1 - \frac{2}{3}\cos 2\,\omega t - \frac{2}{15}\cos 4\omega t - \frac{2}{35}\cos 6\omega t\right) \quad (1)$$

where V_M represents the peak value of the ac voltage applied to the rectifier diode and ω is the angular velocity ($2\pi f$) of the supply frequency. Note that the dc component of the output wave is $2/\pi$ times the crest value of the ac wave, and the lowest frequency component of ripple in the output is twice the supply frequency and has a magnitude that is two-thirds the dc component of the output voltage. The remaining ripple components are harmonics of this lowest frequency component and diminish in amplitude with the order of the harmonic involved in accordance with Equation 1.

Table 1 gives the results of the analyses(1) for the output waves delivered by several popular polyphase rectifier connections. The ripple voltages are much less for the three-phase half-wave rectifier than for the single-phase connection, and are still less for the six-phase arrangements. In all cases, the amplitude of the ripple components diminishes rapidly as the order of the harmonics is increased.

Input Inductance Requirements

To achieve normal choke-input operation, it is necessary that there be a continuous flow of current through the input inductance. The peak value of the alternating current flowing through the input inductance must, hence, be less than the dc output current of the rectifier. The value for minimum inductance, called critical inductance L_C is derived as follows:

The average or dc current is $V_{L(DC)}/R_L$. The peak alternating current is very nearly the peak value $V_{M1}/\omega_1 L$ of the fundamental-frequency component, since the higher-frequency components of the ripple current are relatively small. The ripple harmonics are smaller than given by Equation 1, because of the higher reactance of the inductor at the harmonic frequencies. The ratio of peak-to-average current therefore closely approximates $(V_{M1}/V_{DC})/\omega L_C/R_L$, which must not be less than unity. For a single-phase, full-wave circuit, the fundamental ripple component ω_1 is twice the input frequency ω_i; also, the ratio V_{M1}/V_{DC} is the coefficient (2/3) of the fundamental ripple frequency term ($\cos 2\omega t$) in Equation 1. After substituting $2\omega_i$ for ω_1 and 2/3 for V_{M1}/V_{DC} into the previous expression, the following equation for critical inductance is found:

$$L_C = \frac{R_L}{3\omega_i} \quad (2)$$

Using a similar procedure for polyphase rectifiers, the critical inductance is found to be

$$L = \frac{2R_L}{m(m^2 - 1)\omega_i} \quad (3)$$

*See page 107 for derivation.

In Equations 2 and 3.

L_C = the critical inductance in henries,

R_L = the load resistance in ohms. If the resistance of the choke, diode, or transformer is significant, the values should be added to R_L,

ω_i = the input or line frequency in rad/sec,

m = the effective phase number for the output wave.

For convenience, Equations 2 and 3 are put in the form

$$L_C = R_L/A, \tag{4}$$

where A is a constant determined from Figure 3. The critical inductance required in polyphase systems is considerably less than required in a single-phase system.

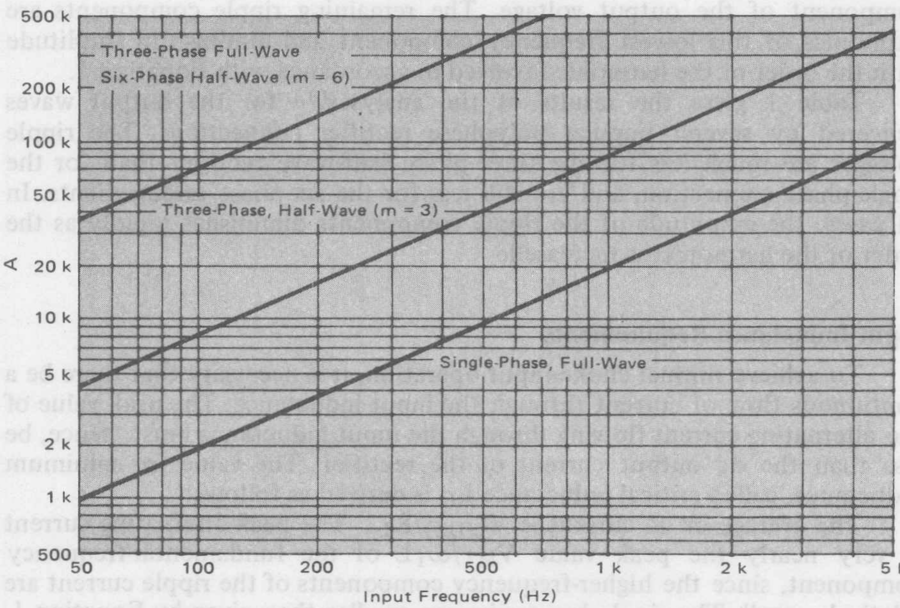


Figure 3 – Values for the Constant A used to compute Critical Inductance

The higher the load resistance, i.e., the lower the dc load current, the more difficult it is to maintain a continuous flow of current. Also, with a given L, continuous flow will not occur when the load resistance exceeds a critical value.

When the inductance is less than the critical value, the system acts as a capacitor-input system, described later. When the load current varies from time to time, it is necessary to satisfy the equations at all times if proper operation, and in particular, good voltage regulation are to be maintained. In order that this requirement may be satisfied at very small load currents without excessive inductance, it is necessary to place a resistance (commonly termed a "bleeder" resistance) across the output of the rectifier-filter system in order to limit R_L to a value corresponding to a reasonable value of L_C.

superimposed upon the dc magnetization. Incremental inductance always increases as the dc magnetization decreases. This fact is of assistance in satisfying the equations at low load currents where R_L is large and can be put to advantage by the use of a "swinging" choke in which the inductance is varied by the load current using a controlled approach to saturation that lowers inductance as current increases.

It is also important that series resonance between the input choke and first filter capacitor is avoided. Since at resonance, $1/\omega_1 L = \omega_1 C$, to avoid resonance it is sufficient to insure that

$$\omega_1{}^2 LC > 2$$

where ω_1 is the lowest frequency component of the ripple.

The output ripple magnitude depends upon the values of the choke and the capacitor used. It is calculated as shown in subsequent sections.

Voltage Regulation in Choke Input Systems

Given ideal components, the voltage regulation of a rectifier-filter system employing input inductance greater than the critical value would be perfect, i.e., voltage output would be independent of load current. In practice, the output voltage falls off with increasing load as a result of resistances in the diodes, filter, and transformer and as a result of the leakage reactance of the supply transformer. The various resistances in the circuit reduce the output voltage without affecting the waveshapes in the system. The leakage reactance of the transformer, however, distorts the waveshape of the output voltage by preventing the current from shifting instantly from one transformer winding to another, as in the ideal cases of Figure 1. The situation in a typical case is shown in Figure 4 where μ represents the time interval required to transfer the current. During this transition period, the output voltage assumes a value intermediate between the open-circuit voltages of the two windings that are simultaneously carrying current, as shown, instead of following the open-circuit potential of the more positive anode as is the case in an ideal system. As a result, the average voltage of the output is less than if no leakage inductance were present by the amount indicated by the shaded areas. The quantitative relations, which are quite complicated, depend upon both the rectifier and the transformer connections.

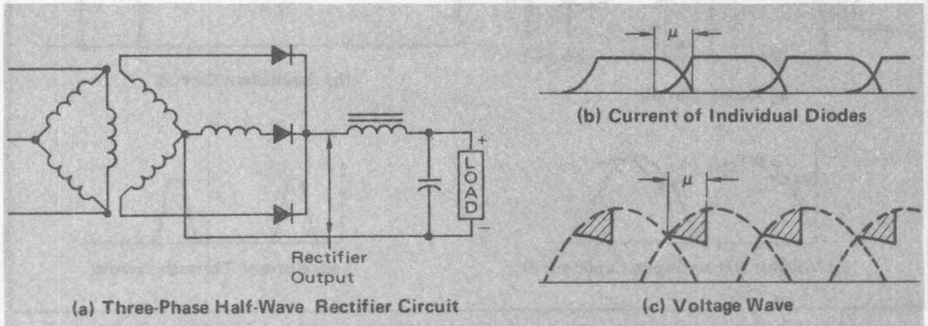


Figure 4 – Effect of transformer leakage inductance on the behavior of a polyphase rectifier

When the input inductance is less than the critical value, the output voltage rises, and when the load resistance is very large, the output voltage will approach the peak value of the rectifier output waveform causing the system to have poor voltage regulation. When the load current is small, the energy stored in the inductor is also small and the inductor is essentially out of the circuit.

BEHAVIOR OF RECTIFIERS USED WITH CAPACITOR-INPUT FILTERS

The rectifier-filter system illustrated in Figure 5 differs from that of Figure 1 in that a shunt capacitor is presented to the rectifier output. Each time the positive peak alternating voltage is applied to one of the rectifier anodes, the input capacitor charges up to just slightly less than this peak voltage. No current is delivered to the filter until another anode approaches its peak positive potential. When the capacitor is not being charged, its voltage drops off nearly linearly with time because the first filter inductance draws a substantially constant current. A typical set of voltage and current waveforms is shown in Figures 5c and d. Note that use of an input capacitor increases the average voltage across the output terminals of the rectifier and reduces the amplitude of the ripple in the rectifier output voltage.

Analysis of Rectifiers with Capacitor-Input Systems

The detailed action that takes place in a capacitor-input system depends in relatively complicated way upon the load resistance in the rectifier output, the input filter capacitance, the leakage reactance and resistance of the transformer, and the characteristics of the rectifier diode. For purposes of analysis, the actual rectifier circuit, such as that of Figure 5a, is replaced by the equivalent circuit of Figure 5b. The diode is replaced by switch S, which closes only when one of the diodes conducts current. The transformer is replaced by an equivalent generator having a voltage equal to the open-circuit line to center-tap secondary voltage and having equivalent internal

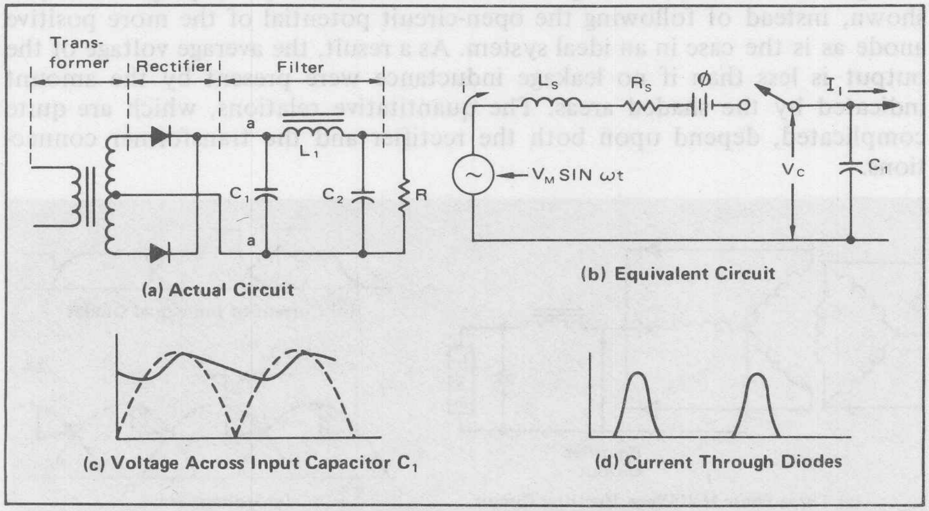


Figure 5 — Actual and equivalent circuits of capacitor-input rectifier system, together with oscillograms of voltage and current for a typical operating condition.

impedance elements L_S and R_S. The inductance L_S is the leakage inductance of the transformer, measured across one-half the secondary winding with the primary short-circuited. The source resistance R_S is the corresponding transformer resistance plus a resistance to account for the resistance of the diode. In very low voltage systems, a small potential ϕ may be needed to accurately account for the diode voltage drop. The input capacitor of the filter system is C_1, and the first inductance L_1 is assumed to draw a constant current I_1 equal to the dc voltage developed across the input capacitor divided by the sum of the actual load resistance plus the resistance of the filter inductance.

By utilizing the equivalent circuit of Figure 5b, the effects that result from changes in circuit proportions may be deduced. Thus a decrease in the load resistance, i.e., an increase in the dc output current, reduces the average or dc output voltage, increases the ripple voltage, and increases the length of time during which the diode is conducting, as illustrated in Figure 6a. Increasing the input capacitance has as its principal effect a decrease in the ripple voltage and also causes the average voltage to be increased slightly; these effects are shown in Figure 6b. Increasing the leakage inductance (or resistance) of the transformer, reduces the average output voltage as illustrated in Figure 6c, and likewise decreases the ratio of peak-to-average current flowing through the rectifier diode. In the case of a source and diode having very low impedance, the situation is as illustrated in Figure 6d, and the peak current becomes quite high.

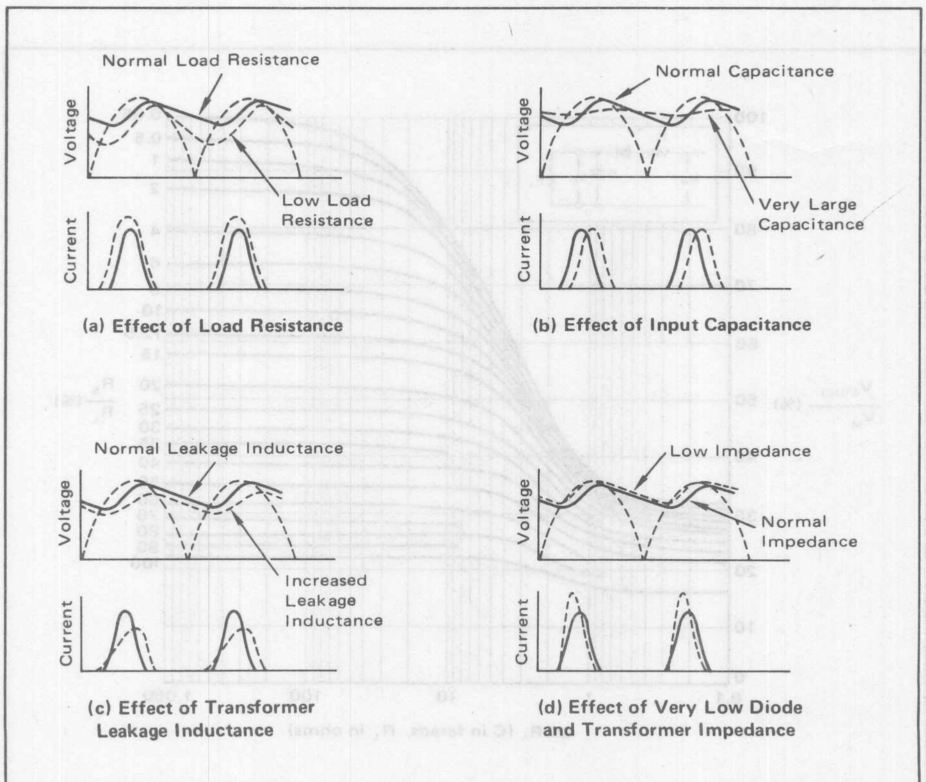


Figure 6 — Effects of circuit constants and operating conditions on behavior of rectifier operated with capacitor-input filter.

Design of Capacitor-Input Filters

The best practical procedure for the design of capacitor-input filters still remains based on the graphical data presented by Schade[2] in 1943. The curves shown in Figures 7 through 10 give all the required design information for half-wave and full-wave rectifier circuits. Whereas Schade originally also gave curves for the impedance of vacuum-tube rectifiers, the equivalent values for semiconductor diodes must be substituted. However, the rectifier forward drop often assumes more significance than the dynamic resistance in low-voltage supply applications, as the dynamic resistance can generally be neglected when compared with the sum of the transformer secondary-winding resistance plus the reflected primary-winding resistance. The forward drop may be of considerable importance, however, since it is about 1 V, which clearly cannot be ignored in supplies for 12 V or less.

Returning to the above curves, the full-wave circuit will be considered. Figure 8 shows that a circuit must operate with $\omega CR_L \geqslant 10$ in order to hold the voltage reduction to less than 10 percent and $\omega CR_L \geqslant 40$ to obtain less than 2 percent reduction. However, it will also be seen that these voltage-reduction figures require R_S/R_L, where R_S is now the total series resistance, to be about 0.1% which, if attainable, causes repetitive peak-to-average current ratios from 10 to 17 respectively, as can be seen from Figure 9. These ratios can be satisfied by many diodes; however, they may not be able to tolerate the turn-on surge current generated when the input-filter capacitor is discharged and the transformer primary is energized at the peak of the input

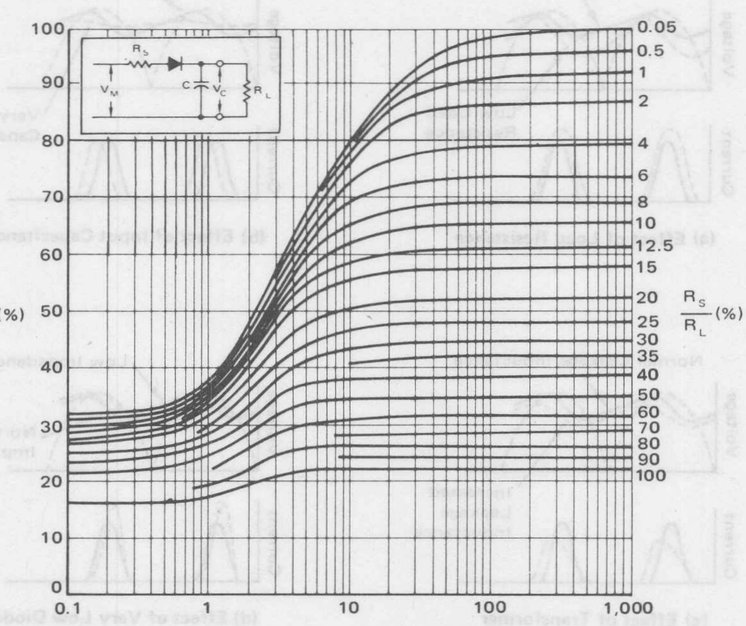


Figure 7 — Relation of applied alternating peak voltage to direct output voltage in half-wave capacitor-input circuits. *(From O. H. Schade, Proc. IRE, vol. 31, p. 356, 1943.)*

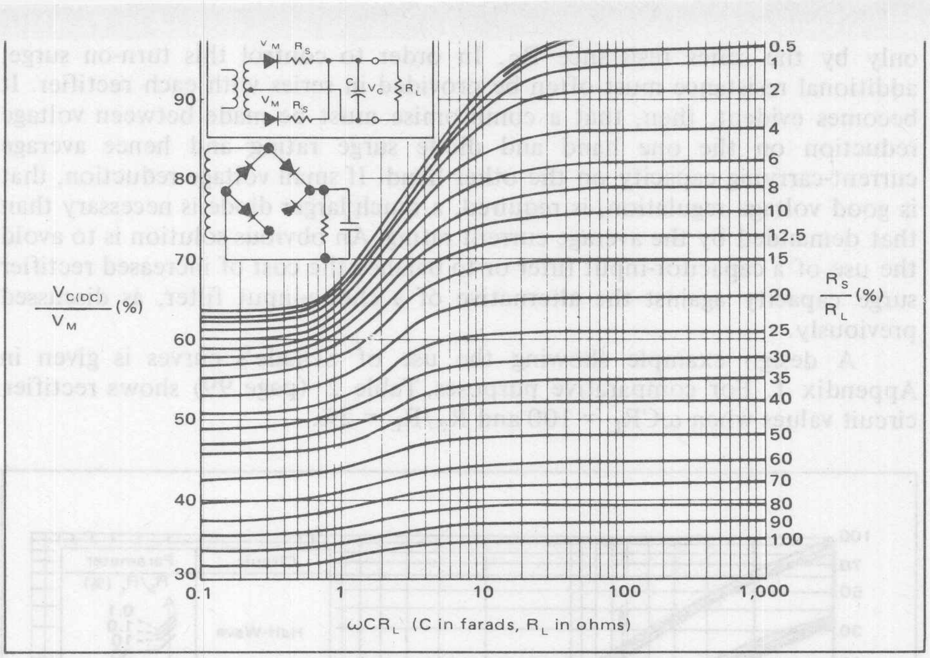
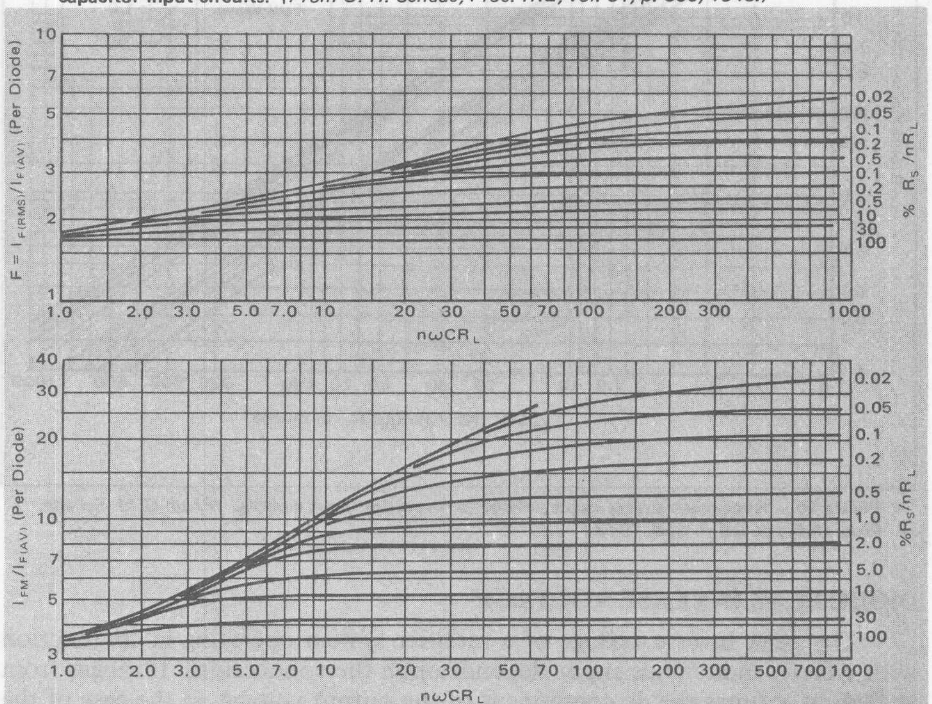


Figure 8 – Relation of applied alternating peak voltage to direct output voltage in full-wave capacitor-input circuits. *(From O. H. Schade, Proc. IRE, vol. 31, p. 356, 1943.)*



$n = \begin{cases} 1 & \text{For Half-Wave Single-Phase Rectifier Circuits} \\ 2 & \text{For Full-Wave Single-Phase Rectifier Circuits} \end{cases}$ C in Farads; R_L in Ohms

$\omega = 2\pi f$ where f = Line Frequency; R_S = RMS Equivalent Source Resistance

Figure 9 – Relation of RMS and peak to average diode current in capacitor-input circuits. *(From O. H. Schade, Proc. IRE, vol. 31, p. 356, 1943.)*

waveform. The rectifier is then required to pass a surge current determined by the peak secondary voltage less the rectifier forward drop and limited only by the series resistance R_S. In order to control this turn-on surge, additional resistance must often be provided in series with each rectifier. It becomes evident, then, that a compromise must be made between voltage reduction on the one hand and diode surge rating and hence average current-carrying capacity on the other hand. If small voltage reduction, that is good voltage regulation, is required, a much larger diode is necessary than that demanded by the average current rating. An obvious solution is to avoid the use of a capacitor-input filter or to balance the cost of increased rectifier surge capacity against the alternative of a choke-input filter, as discussed previously.

A design example showing the use of Schade's curves is given in Appendix 1. For comparative purposes, Table 2 (page 99) shows rectifier circuit values when $\omega CR_L = 100$ and $R_S/R_L = 2\%$.

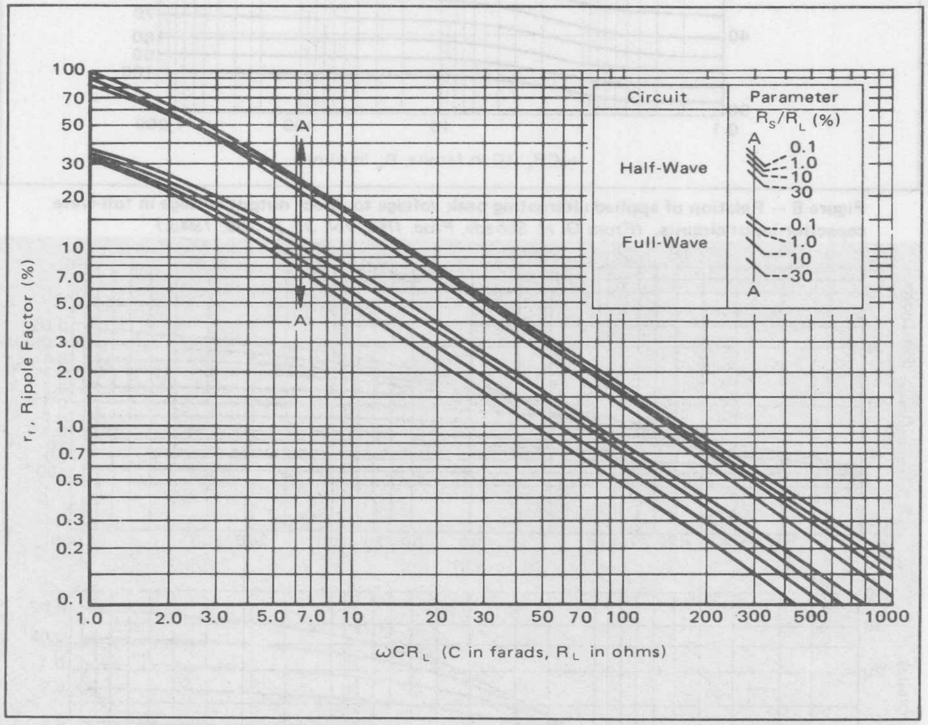


Figure 10 – Root-mean-square ripple voltage for capacitor-input circuits. *(From O. H. Schade, Proc. IRE, vol. 31, P. 356, 1943.)*

DIODE PEAK INVERSE VOLTAGE

The peak inverse voltage of a rectifier system operating in conjunction with a series-inductance input depends upon the connections. It ranges from as high as π times the dc component of the output voltage, in the case of the single-phase center-tapped connection, to barely more than the dc voltage in the three-phase full-wave bridge. Results in typical cases are given in Tables 1 and 2 and are seen to be the same as determined for the resistive load circuits in Chapters 4 and 5.

The peak inverse voltage PIV applied to the rectifiers in capacitor-input systems is generally based upon the capacitor charging to V_M, which is the case when the load is light and the capacitor large. However, since the peak of the reverse voltage sine wave occurs sometime after the capacitor has been charged, PIV is somewhat less than 2 V_M as shown by Figure 11.

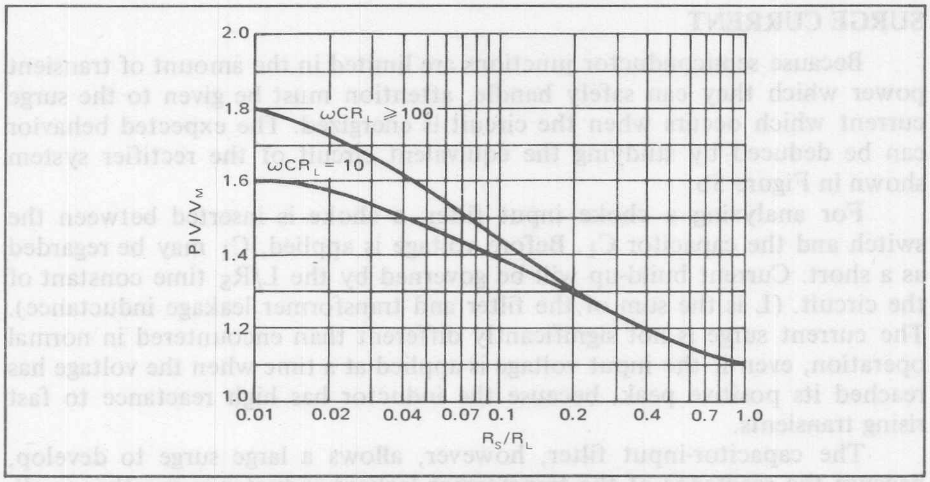


Figure 11 — Ratio of operating peak inverse voltage to peak applied ac for rectifiers used in capacitor-input, single-phase, filter circuits

TRANSFORMER CONSIDERATIONS

The ratio of the actual dc rectified power output to the volt-ampere capacity of the windings on the basis of sinusoidal waves, for the same heat loss due to winding resistance, is termed the transformer utilization factor (UF). Its value depends upon the rectifier connections and is, in general, not the same for the primary and secondary windings, since the waveshapes in these windings will generally be different. Table 1 shows the reciprocal of the UF of the primary and secondary windings for some of the more commonly used rectifier connections. Derivation of the values is handled as shown for the resistive load circuits discussed in Chapter 4.

The wave shapes of the currents that flow through the windings of the transformer in the idealized case of a rectifier system operating with an infinite input inductance are shown in Figure 2 for two typical cases. Because these waves are not sinusoidal, the heating of the transformer windings is greater for a given dc power output from the rectifier than would be the case if the same amount of ac power were delivered by the transformer to a resistance load. It is accordingly necessary to design the transformer windings more generously for rectifier applications than for cases where sinusoidal currents are involved.

Since transformer volt-ampere ratings vary with the rms content of the rectifier circuit, they must be calculated for each capacitive-input filter design. Higher R_S/R_L ratios help reduce transformer requirements. Also, the effects of transformer satuation and finite bandwidth cannot be ignored. The former tends to limit the peak current while the latter allows the capacitor to charge over a longer time and hence reduces the charging current $i = C\, dv/dt$. Core saturation generally occurs on the recurrent charging peaks,

observing the voltage waveform induced in an unloaded winding on the same core.

SURGE CURRENT

Because semiconductor junctions are limited in the amount of transient power which they can safely handle, attention must be given to the surge current which occurs when the circuit is energized. The expected behavior can be deduced by studying the equivalent circuit of the rectifier system shown in Figure 5b.

For analyzing a choke input filter, a choke is inserted between the switch and the capacitor C_1. Before voltage is applied, C_1 may be regarded as a short. Current build-up will be governed by the L/R_S time constant of the circuit. (L is the sum of the filter and transformer leakage inductance). The current surge is not significantly different than encountered in normal operation, even if the input voltage is applied at a time when the voltage has reached its positive peak, because the inductor has high reactance to fast rising transients.

The capacitor-input filter, however, allows a large surge to develop, because the reactance of the transformer leakage inductance is rather small. The maximum instantaneous surge current is approximately V_M/R_S and the capacitor charges with a time constant $\tau \approx R_S C_1$. As a rough – but conservative – check, the surge will not damage the diode if V_M/R_S is less than the diode I_{FSM} rating and τ is less than 8.3 ms. It is wise to make R_S as large as possible and not pursue tight voltage regulation; therefore, not only will the surge be reduced but rectifier and transformer ratings will more nearly approach the dc power requirements of the supply.

COMPARISON OF CAPACITOR-INPUT AND INDUCTANCE-INPUT SYSTEMS

The basis for distinguishing between inductance-input and capacitor-input systems is that in the former the current flows continuously from the rectifier output into the filter systems, while in the latter the current flows intermittently from the rectifier into the filter. Intermittent action is also present with inductance input systems when the input inductance is less than the critical value. When this is the case, the system is classified as a capacitor-input arrangement even though it possesses a series inductance.

A comparison of the performance of inductance-input and capacitor-input systems shows that in the latter arrangement the dc voltage is higher, the ripple voltage more, the surge current higher, and the voltage regulation poorer, than when inductance input is used with the same diode, transformer, load resistance, and capacitance. Also, with capacitor input the ripple voltage increases with increasing load current, unlike the inductance-input system where the ripple voltage is independent of load current. The utilization factor of the power transformer is much poorer with the capacitor-input system because of the higher ratio of peak-to-average current flowing through the rectifier diode, and likewise the diode is less efficiently utilized. The characteristics of the various popular rectifier systems are shown in Table 2.

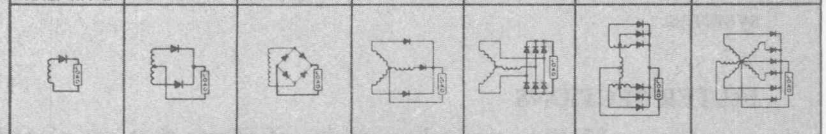
RECTIFIER CIRCUIT CONNECTION		SINGLE-PHASE HALF-WAVE	SINGLE-PHASE FULL-WAVE CENTER-TAP	SINGLE-PHASE FULL-WAVE BRIDGE	THREE-PHASE HALF-WAVE STAR	THREE-PHASE BRIDGE	THREE-PHASE DOUBLE WYE WITH INTERPHASE	THREE-PHASE FULL-WAVE STAR
								
VOLTAGE WAVESHAPE TO LOAD OR FILTER								
CHARACTERISTIC	LOAD							
Average Current Through Diode $I_{F(AV)}/I_{L(DC)}$	R,L&C*	1.00	0.50	0.50	0.333	0.333	0.167	0.167
Peak Current Through Diode $I_{FM}/I_{F(AV)}$	R	3.14	3.14	3.14	3.63	3.15	3.15	6.30
	L*	–	2.00	2.00	3.00	3.00	3.00	6.00
	C	8.0	8.0	8.0	DATA NOT AVAILABLE			
Form Factor of Current Through Diode $I_{F(RMS}$ $_{F(AV)}$	R	1.57	1.57	1.57	1.76	1.74	1.76	2.46
	L*	–	1.41	1.41	1.73	1.73	1.73	2.45
	C	2.7	2.7	2.7	DATA NOT AVAILABLE			
RMS Current Through Diode $I_{F(RMS)}/I_{L(DC)}$	R	1.57	0.785	0.785	0.587	0.579	0.293	0.409
	L*	–	0.707	0.707	0.578	0.578	0.289	0.408
	C	2.7	1.35	1.35	DATA NOT AVAILABLE			
RMS Input Voltage Per Transformer Leg $V_i/V_{L(DC)}$	R&L	2.22	1.11	1.11	0.855	0.428	0.855	0.741
	C	0.707	0.707	0.707	0.707	0.408	0.707	0.707
Diode Peak Inverse Voltage (P I V) $V_{RRM}/V_{L(DC)}$	R&L	3.14	3.14	1.57	2.09	1.05	2.42	2.09
	C	2.00	2.00	1.00	2.00	1.00	2.00	2.00
Transformer Primary Rating VA/P_{DC}	R	3.49	1.23	1.23	1.23	1.05	1.06	1.28
	L	–	1.11	1.11	1.21	1.05	1.05	1.28
Transformer Secondary Rating VA/P_{DC}	R	3.49	1.75	1.23	1.50	1.05	1.49	1.81
	L	–	1.57	1.11	1.48	1.05	1.48	1.81
Total RMS Ripple, %	R	121	48.2	48.2	18.2	4.2	4.2	4.2
Lowest Ripple Frequency, f_r/f_i		1	2	2	3	6	6	6
Rectification Ratio (Conversion Efficiency),%	R	40.6	81.2	81.2	96.8	99.8	99.8	99.8
	L*		100	100	100	100	100	100

TABLE 2: SUMMARY OF SIGNIFICANT RECTIFIER CIRCUIT CHARACTERISTICS. CAPACITIVE DATA IS FOR $\omega CR_L = 100$ & $R_S/R_L = 2.0\%$

*Inductive data valid when the circuit input voltage is a square wave, resistive or inductive load.

$P_{DC} = I^2_L R_L$ (R_S neglected) $V_L = I_L R_L$

Shunt capacitor-input arrangements are generally employed in radio and television receivers, high fidelity sound systems, small public-address systems, etc., when the amount of dc power required is small. They must be used with half-wave rectifiers and are attractive when the input power is taken directly from the ac line without a power transformer. In contrast, inductance-input arrangements are used when the amount of power required is large, since then the higher utilization factor and lower peak currents result in important savings in rectifier and transformer costs. Inductance input is also always employed when good regulation of the dc voltage is important but the precision of an electronic regulator circuit is not needed. Inductance-input systems are always employed in polyphase rectifier systems.

FILTER SECTIONS

Figure 12 gives typical examples of filters that are placed between the rectifier output and the load to make the current delivered to the load substantially pure direct current. These filters are made up of series impedances (either inductances or resistances) that oppose the flow of alternating current from the rectifier output to the load and shunt capacitors that by-pass the alternating currents that succeed in flowing through the series impedances.

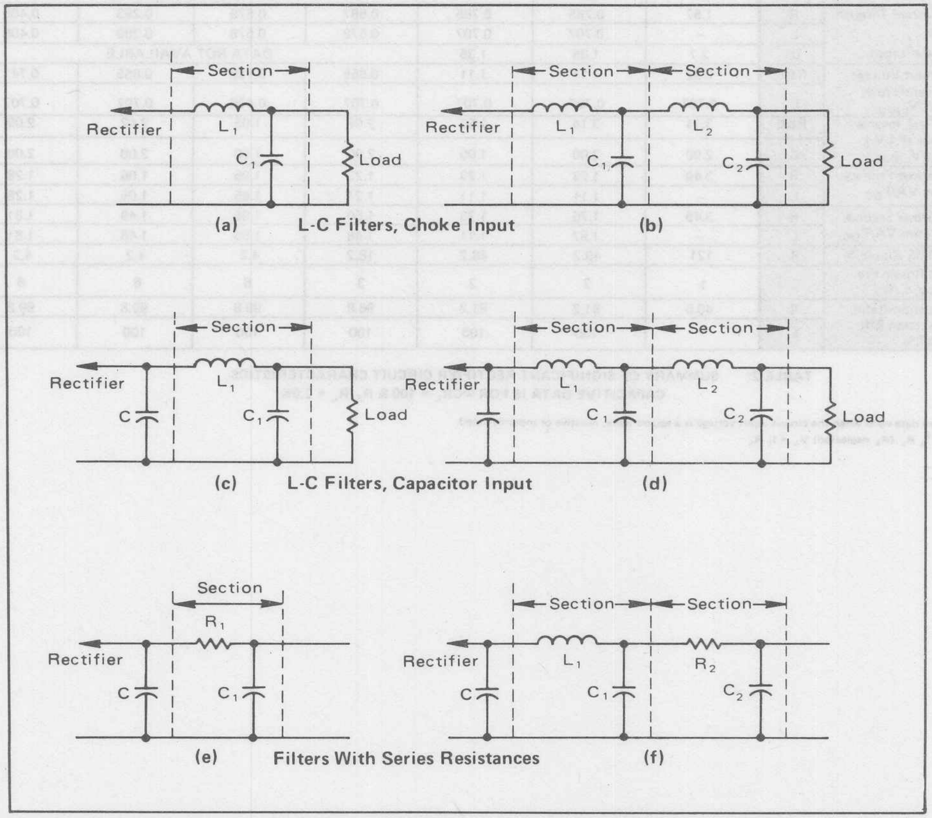


Figure 12 – Typical L and π Section Filters

For purposes of discussion and analysis, filters are ordinarily divided into sections, each of which consists of a series impedance followed by a shunt capacitor, as indicated in Figure 12. It will be noted that in this classification the inductance in an inductance-input system is considered to be part of the first section of the filter. However, a shunt capacitance across the rectifier output is not included as part of a filter section, but rather is considered to be part of the rectifier system, which delivers to the first filter section a voltage corresponding to the voltage developed by the rectifier across the input capacitor.

Voltage and Current Relations in Filters

The input voltage to the filter is whatever output voltage is developed by the rectifier connection in the case of inductance-input systems (it is the same as with a resistive load), or is the voltage developed across the shunt capacitor in the case of capacitor-input systems. The ripple voltage in the output of the rectifier-filter system is then the alternating component of this input voltage reduced by the action of the filter sections.

Most filter sections are composed of a series inductance and a shunt capacitance. In practical filters of this type, the reactance of the shunt capacitance at the lowest ripple frequency is much smaller than the resistance of the load (or the reactance of the series inductance of the following section). Substantially all ripple current entering the inductance L of the section flows through the capacitance C of the filter section. The current in the section is then $V_i/(\omega L - 1/\omega C)$, where V_i is the alternating voltage applied across the input to the filter section. The voltage that this current develops in flowing through the capacitor C is $(1/\omega C)V_i/(\omega L - 1/\omega C) = V_i/(\omega^2 LC - 1)$. Dividing by V_i results in the following relationship for the voltage reduction through an L-C section:

$$\frac{V_o}{V_i} = \frac{1}{(\omega^2 LC - 1)}, \tag{6}$$

where: L = series inductance of filter section,

C = shunt capacitance of section,

$\omega/2\pi$ = frequency of ripple voltage involved.

Results of Equation 6 are given in Figure 13 for the usual case where the ripple components are harmonics of 60 Hz. Figure 14 indicates the actual ripple output of a full-wave single-phase rectifier circuit.

When the current drawn by the load impedance is small, the series inductance of the LC filter may be replaced by a series resistance as shown in Figures 12e and f. This arrangement is widely used in resistance-coupled amplifiers, tuned radio-frequency amplifiers, etc., and has the advantage that a resistance is much less expensive than an inductance of corresponding effectiveness. The disadvantage is the dc voltage drop and power loss that occur in the resistance; these losses limit the resistance-capacitance type of filter to cases where the current is small and where a moderate dc voltage drop is permissible.

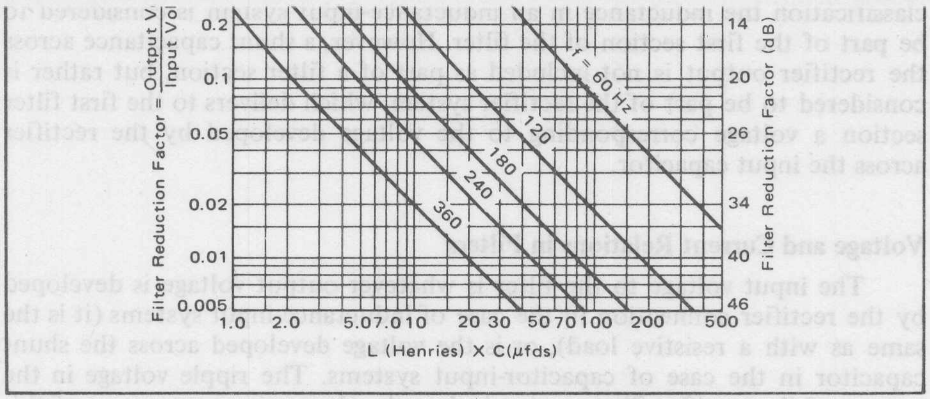


Figure 13 — Reduction in ripple voltage produced by a single section inductance-capacitance filter at various ripple frequencies.

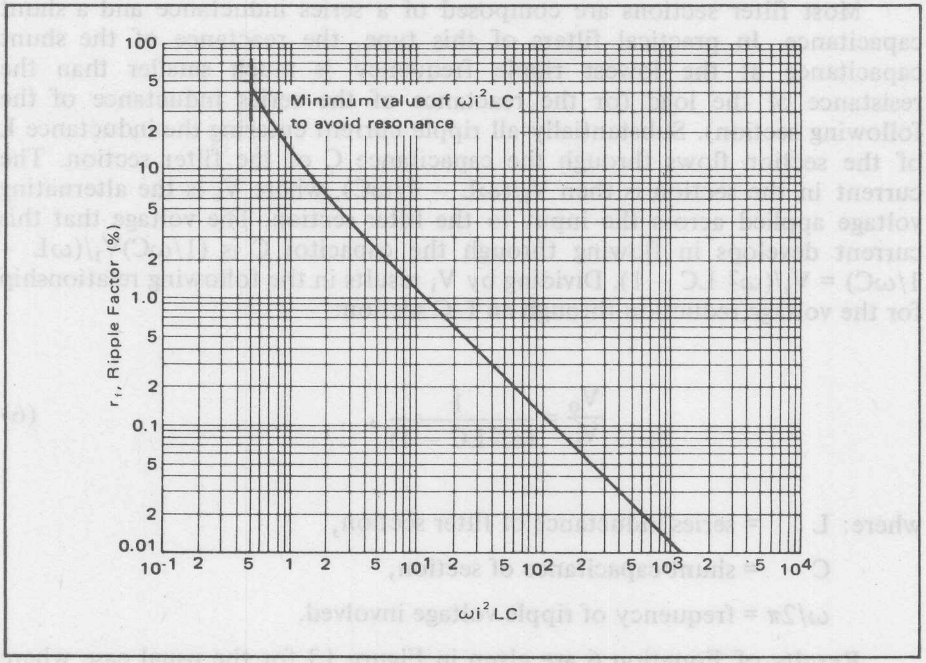


Figure 14 — Ripple factor for single-section LC filter for full-wave input.

In practical resistance capacitance filters, the reactance of the shunting capacitor is always made small compared to the series resistance of the filter and to the impedance to which the output of the filter section is connected. The ripple current flowing in R is $V_i/\sqrt{R^2 + (1/\omega C)^2} \approx V_i/R$, where V_i is the ripple voltage applied to the section. The ripple output voltage of the section results from the current V_i/R flowing through the reactance $1/\omega C$ of the capacitance C of the section, and hence is $V_i/R\omega C$. Therefore, a section of resistance-capacitance filter reduces each frequency component of voltage applied to the input side according to the approximate relation

$$\frac{V_o}{V_i} = \frac{1}{R\omega C}, \tag{7}$$

where R is the series resistance and C is the shunt capacitance (see Figure 12e).

When a filter consists of more than one section, the total reduction in ripple voltage produced by the several sections is very nearly the product of the voltage-reduction factors of the individual sections. The effectiveness of the filtering accordingly increases rapidly with the number of sections. For many applications, a single section is entirely adequate, particularly with polyphase rectifiers. Only in special cases, such as audio-frequency amplifiers with very high gain, will the number of sections required exceed two, and then only for those parts of the amplifier that operate at very low signal-power levels.

Graded Filters

When the output of a rectifier-filter system is called upon to supply voltages for several stages of an amplifier system, ordinarily the amount of ripple or hum voltage that can be tolerated is least for those stages that operate at the lowest signal-power levels. This makes it desirable to arrange the filter system so that the voltages applied to different circuits operated from the rectifier-filter system undergo different amounts of filtering.

For example, the output stage of an audio amplifier obtains its collector voltage directly from the input capacitor, which is permissible because of the high power level at which the output stage operates, combined with the hum-suppressing action of the usually used push-pull connection. Progressively increased filtering is provided for the lower level stages, care being taken to design the system so that the reduction in ripple voltage introduced by the filter between stages is at least as great as the amplification of the stages.

A graded filter reduces to the lowest possible value the magnitude of the currents that must be carried by the series impedance arms of the filter and often makes it practical to use resistance-capacitance filter stages in parts of the system, as illustrated in Figure 12. This results in substantial economy in cost, weight, and size, compared to an arrangement in which the entire rectifier output is subject to the maximum amount of filtering. A graded filter also provides isolation or decoupling between stages, thereby reducing regeneration.

Filter Component Selection

The inductance coils used in a filter must have laminated iron cores with an air gap that is sufficient to prevent the dc magnetization from saturating the core. The inductance that is effective in the filter is the incremental inductance, which depends both upon the dc and the ac magnetizations of the core. In estimating the ac magnetization that can be expected, it is normally assumed that the alternating current flowing in the inductance is equal to the voltage of the lowest ripple frequency applied across the input of the filter section, divided by the reactance of the inductance of the section. The alternating magnetization in the inductance

of the first section may be relatively large, whereas the alternating magnetization for the inductances of the other filter sections will be very small if the first section is at all effective.

The capacitors used in filters must be capable of continuously withstanding a dc voltage equal to the peak voltage applied to the rectifier. Electrolytic capacitors are ordinarily used where the peak voltages do not exceed 400 to 500 volts. Such capacitors have very low cost in proportion to capacitance, but they possess the disadvantage of a limited life. Paper and oil capacitors are used at higher voltages and also find use at lower voltages where long life is more important than low cost.

EXAMPLE OF POWER SUPPLY DESIGN

Information given in this chapter is used to design a power supply for an audio amplifier in a home entertainment center. Since electronic regulation is not economically feasible for such applications, the dc supply voltage will be obtained from a 120 V, single-phase line. The supply will consist of a stepdown transformer, rectifier diodes, and a capacitive-input filter as shown in Figure 15.

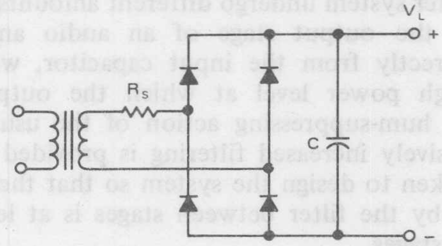


Figure 15 – Bridge Circuit Used for Example Design

Design Constraints

For this example, a supply is to be designed to meet the power requirements of a 20 watt stereo amplifier (operating in an ambient temperature of 55°C) which must drive 8 ohm speaker loads. The output power transistors will be in a totem pole configuration and operate from a single dc supply. Theoretically, a 36 Volt supply would be adequate, but a full load voltage of 40 V is required to make up for transistor and resistive losses. The average current drawn from both channels at rated power out (20 W per channel) is 1.43 A. To minimize distortion, idle current is 50 mA per channel. At zero signal the ripple is critical and must be held to 400 mV maximum so that no hum is detectable. Regulation is not critical, but it is desirable to keep the no load voltage below 50 Volts to ease the voltage requirements of the output transistors.

From the previous discussion, the power supply specifications are summarized in terms of the constants required:

1) $\omega = 2\pi f = 377$ rad/sec,

2) $R_L = V_{L(DC)}/I_{L(DC)}$,
$= 40/1.43 = 28\Omega$ at full load,
$= 50/0.1 = 500\Omega$ at idle,

3) $V_{L(DC)}$ (full load/$V_{L(DC)}$ (idle) $= 80\%$,

4) $r_f = 400$ mV/50 V $= 0.8\%$.

Passive Component Selection

The choice of circuit is between a single-phase full-wave center-tap or a full-wave bridge circuit as outlined in Table I of Chapter 4. The center-tap requires only two diodes, but it has the disadvantages of requiring an additional winding, causing a poorer transformer utilization factor, and doubling the required voltage ratings of the diodes. The deciding factor in favor of using the bridge rectifier circuit is its higher secondary utilization factor. This is an important consideration when using a capacitive input filter because high rms currents are required from the transformer to obtain good output voltage regulation (i.e., a low R_S/R_L ratio is required).

The curves shown in Figure 10 are used to find a value for C to meet the ripple specification. To use the curves, it is necessary to estimate a value for the R_S/R_L ratio. This can be done by referring to Figure 8 and assuming that the idle dc voltage equals the peak of the input voltage and that the ωCR_L product is large enough to place operation in the right hand plateau of Figure 8. Based on these assumptions, note that to hold $V_{L(DC)}/V_M$ above 80%, $R_S/R_L < 7\%$. If it is desired to minimize* C, then operation may move into the knee region and R_S/R_L may need to be made considerably less than 7% to hold $V_{L(DC)}/V_M$ to 80%.

From Figure 10, at $r_f = 0.8\%$, $R_S/R_L = 1\%$ (being conservative), read $\omega CR_L = 90$. $\therefore C = 90/(377)(500) = 496\mu F$ and a standard value of $500\mu F$ can be used.

A suitable value for R_S to maintain the required voltage regulation can be obtained by using Figure 8. Under full load with $C = 500\mu F$, $\omega CR_L = 5.2$. Again assuming that the output voltage at idle equals the peak input voltage, which makes $V_{L(DC)}/V_M = 80\%$, read $R_S/R_L \approx 3.5\%$ at $\omega CR_L = 5.2$. $\therefore R_S = (0.035)(28) \approx 1.0\Omega$. This value may be largely composed of the sum of the transformer secondary resistance, the reflected primary resistance, and the diode dynamic resistance.

At idle, $R_S/R_L = 1.0/500 = 0.2\%$ and, as previously found, $\omega CR_L = 90$. From Figure 8, $V_{L(DC)}/V_M$ is read as 97% which verifies the validity of the assumption that $V_{L(DC)}$ (idle) $= V_M$.

*In many cases, minimizing C will result in lower cost. However, by choosing a larger value of C, R_S may be increased to obtain the same voltage regulation, with the beneficial effects of lower rms and peak surge currents. The lower rms values may result in lower cost for the transformer and diodes such that the overall power supply cost is less.

Transformer Selection

The peak output voltage developed across the capacitive filter has been specified as 50 which requires a transformer secondary rms voltage of 35 V. However, because of the forward voltage drops across the diodes, a standard 36 V transformer may be used. The transformer volt-ampere rating is dependent on rms current which can be obtained from Figure 9. At full load, R_S/R_L = 3.5% and ωCR_L = 5.2. In full-wave circuits, n = 2, the value of $n\omega CR_L$ = 10.4, and R_S/R_L = 3.5%, yielding a diode current form factor of approximately 2.1. The load and secondary form factor, being full-wave, is $1/\sqrt{2}$ times the diode form factor. Consequently, the transformer rating is

$$VA = (36)(1.43)(2.1)/\sqrt{2} = 77.$$

Diode Selection

A diode bridge assembly is recommended for ease of installation. The bridge voltage rating should be at least 20% greater than the peak line voltage, because it may be coupled through the transformer interwinding capacitance when the primary is energized. (See Chapter 9)

In choosing a bridge, the total output current of 1.43 A is used as a selection guide rather than average current per diode. The MDA200 series of bridges with 2.0 A current ratings will be evaluated for this application. It is necessary to determine whether these bridges can handle the repetitive peak currents into the filter and the initial surge current required to charge the filter capacitor.

The steady state peak-to-average current ratio can be obtained from Figure 9. With R_S/R_L = 3.5% and $n\omega CR_L$ = 10.4, a peak-to-average ratio per leg of 7 is interpolated. Consulting Figure 16, taken from the MDA200 data sheet, a peak-to-average ratio of 7 per leg yields a maximum full-wave average current capability of about 1.7 A at 55°C, which exceeds the requirement comfortably.

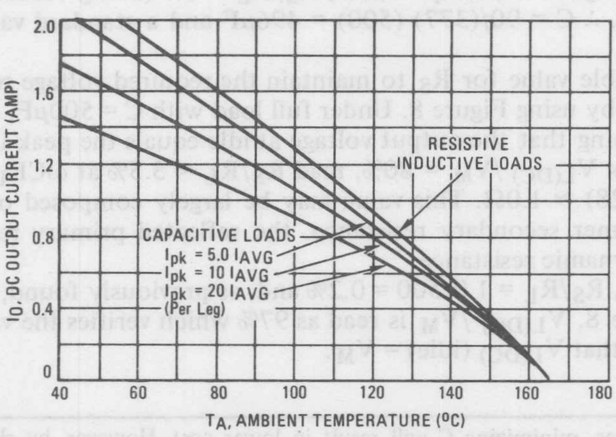


Figure 16 — Derating Data for the MDA200 Bridge Assembly

The MDA200 diode bridge assembly has a surge current rating of 60 A for one cycle, i.e., it will handle two 60 A, half cycle (8.3 ms) surges. The worst case peak surge current in this application is

$$V_M/R_S = 50/1.0 = 50A$$

The time of the surge is the time it will take to charge the capacitor, roughly the time constant of the series resistor and the filter capacitance or

$$t \approx R_S C = (1.0)\,(500)\mu F = 0.5 \text{ ms.}$$

Since the surge current is less than the rating and the time is much less than one cycle, the MDA200 bridge will be satisfactory.

REFERENCES

1. J. Schaefer, *Rectifier Circuits,* John Wiley and Sons, Inc., New York, 1965, p. 258.
2. O. H. Schade, "Analysis of Rectifier Operation," *Proc. IRE,* Vol. 31, No. 7, July, 1943, pp. 343-344, 346-347.

Equation 1, page 89 is derived as follows:

$$\text{DC component} = \frac{V_M}{\pi}\int_{\omega t=0}^{\omega t=\pi} \sin \omega t \, d(\omega t) = \frac{2V_M}{\pi}$$

$$\left.\begin{array}{l}\text{Ripple component of}\\ \text{frequency } n\omega/2\pi\end{array}\right\} = \frac{2V_M}{\pi}\int_{\omega t=0}^{\omega t=\pi} \cos n\omega t \sin \omega t \, d(\omega t)$$

$$= \frac{2V_M}{\pi}\left[\frac{\cos (n-1)\omega t}{2(n-1)} - \frac{\cos (n+1)\omega t}{2(n+1)}\right]_{\omega t=0}^{\omega t=\pi}$$

$$= \frac{2V_M}{\pi}\left(\frac{-2}{n^2-1}\right)$$

In these equations n may have values 2, 4, etc.

CHAPTER 7: RECTIFIER VOLTAGE MULTIPLIER CIRCUITS

Voltage multiplying power supply circuits are often employed when high voltage sources are required, current demand is small, and regulation is not too important.

The principle of operation for all multiplying circuits is essentially the same. Capacitors are charged and discharged on alternate half-cycles of the ac supply voltage. The voltage at the output terminals is the sum of these voltages in series. Thus, the rectifier loading is necessarily capacitive, and high peak currents flow through the rectifier, much like half-wave rectifier circuits with capacitor input filters.

VOLTAGE DOUBLING CIRCUITS

The conventional full-wave voltage doubler is shown in Figure 1. It is the most commonly used voltage doubling circuit.

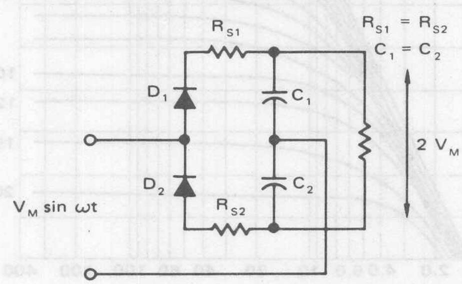


Figure 1 – Conventional Full-Wave Voltage Doubling Circuit

The circuit operates as follows: C_2 is charged to V_M through D_2 and R_{S2} during the negative half-cycle of the supply voltage. During the positive half-cycle, the supply voltage charges C_1 through D_1 and R_{S1}. A voltage of $2V_M$ appears across the output terminals. The capacitors' voltage ratings must be greater than V_M, and the peak voltage rating of the rectifiers, V_{RRM}, must be greater than $2V_M$. The ripple frequency will be twice that of the input supply.

Conventional voltage doubler circuits may be designed from curves similar to those used for capacitor input filters. See Figures 2 through 5.

Voltage doublers have the high inrush and peak repetitive currents encountered with capacitive input filters. The source resistance, R_s, must be chosen to limit the inrush current to a safe level.

As an example, suppose approximately 200 volts dc is required from the ac line to supply a 1k load. A rectifier is selected whose surge rating is 10A.

R_S is selected from.

$$R_S \geqslant V_{M(max)}/I_{FSM}$$
$$\geqslant (1.41)(130)/10 \text{ (High line is taken as 130 volts)}$$
$$\geqslant 19\ \Omega \text{ (use } 20\ \Omega\text{)}.$$

Capacitor size is determined by using Figure 2, which requires that $V_{L(DC)}/V_M$ and R_S/R_L be calculated.

$V_{L(DC)}/V_M = 200/(1.41)(117)$ (Normal line is taken as 117 volts)
$= 1.21.$

$R_S/R_L = 20/1000 = 2\%$

Read $\omega CR_L \approx 7.0$,

$\therefore C = 7.0/\omega R_L = 7.0/(377)(10^3) = 18.6\mu F$. (Use 20 μF).

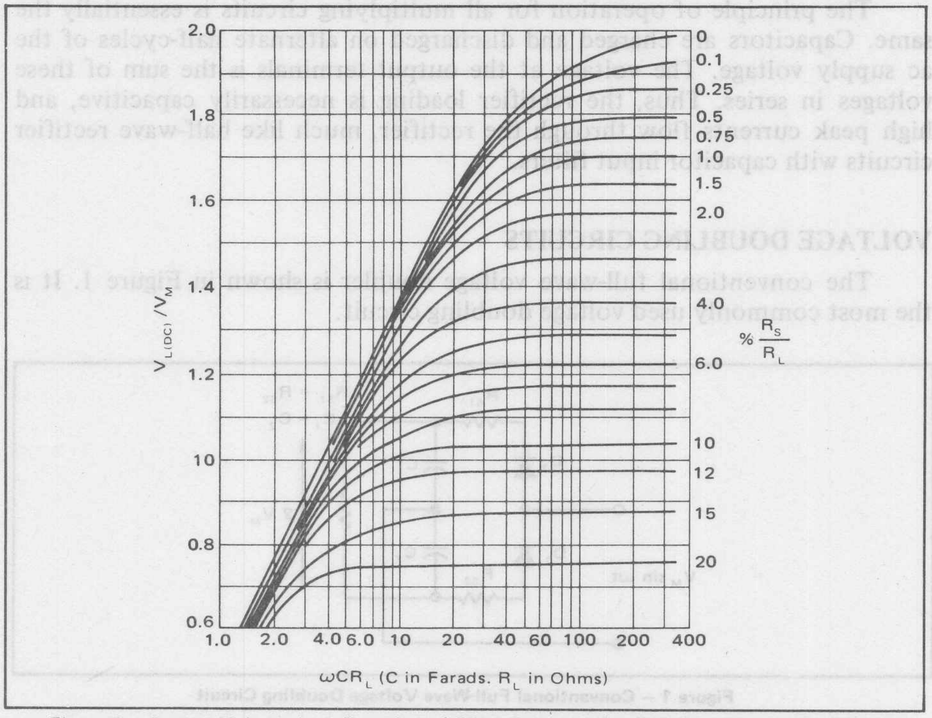


Figure 2 – Output Voltage As A Function of Filter Constants for Full-Wave Voltage Doubler

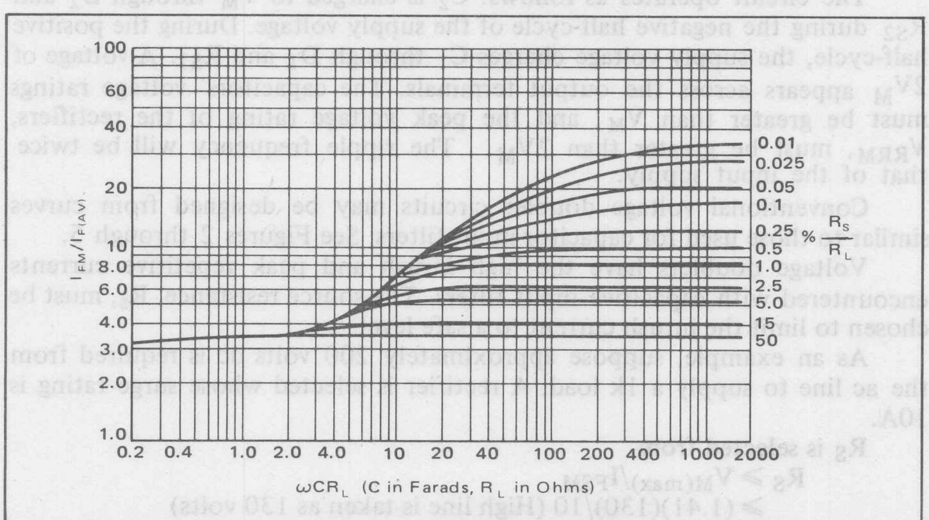


Figure 3 – Peak Rectifier Current As A Function of Filter Constants for Full-Wave Voltage Doubler

With C = 20μF, ωCR_L = 7.54 and the remaining circuit information may be found:

From Figure 3, $I_{FM}/I_{F(AV)}$ = 5.5
From Figure 4, $I_f/I_{F(AV)}$ = 2.2
From Figure 5, r_f = 13%.

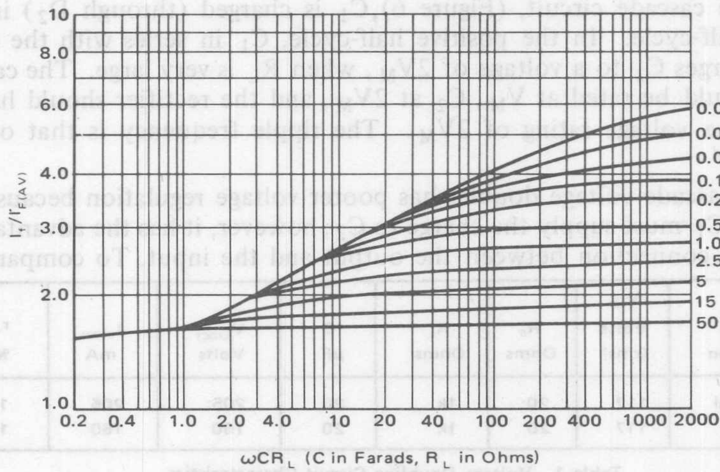


Figure 4 – RMS Rectifier Current As A Function of Filter Constants for Full-Wave Voltage Doubler

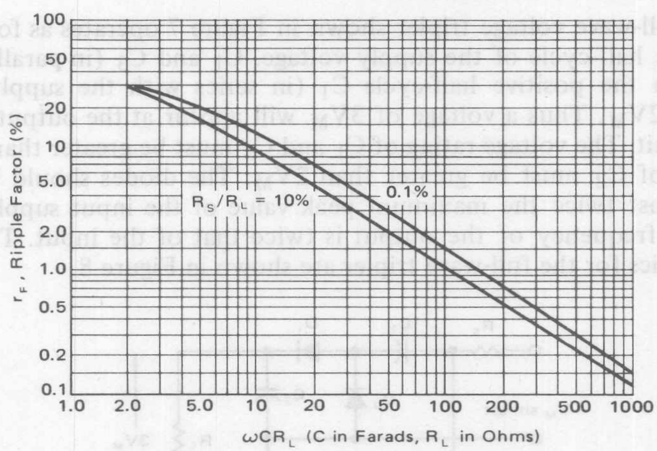


Figure 5 – Ripple As A Function of Filter Constants for Full-Wave Voltage Doubler

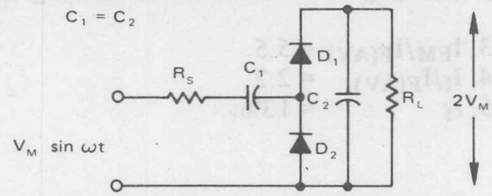


Figure 6 – Cascade (Half-Wave) Voltage Doubling Circuit

In the cascade circuit, (Figure 6), C_1 is charged (through D_2) in the negative half-cycle. In the positive half-cycle, C_1 in series with the input voltage charges C_2 to a voltage of $2V_M$, when R_L is very large. The capacitor C_1 should be rated at V_M, C_2 at $2V_M$, and the rectifier should have a peak inverse voltage rating of $2V_M$. The ripple frequency is that of the input.

The cascade voltage doubler has poorer voltage regulation because the charge on C_1 must supply the charge to C_2; however, it has the advantage of a common connection between the output and the input. To compare the

Circuit Configuration	V_{in} Volts (rms)	R_S Ohms	R_L Ohms	C μF	$V_{L(DC)}$ Volts	$I_{L(DC)}$ mA	r_F %
Conventional	117	20	1k	20	205	205	12.0
Cascade	117	20	1k	20	160	160	16.0

Table 1. Voltage Doubling Circuit Characteristics

two voltage doubling circuits, the circuits may be evaluated using similar components. The resulting characteristics are given in Table 1. Design curves have not been worked out for the cascade circuit. It performs better when C_1 is much larger than C_2.

VOLTAGE TRIPLING CIRCUITS

The full-wave voltage tripler shown in Figure 7 operates as follows: On the negative half-cycle of the supply voltage, C_1 and C_3 (in parallel) charge to V_M. On the positive half-cycle C_1 (in series with the supply voltage) charges to $2V_M$. Thus a voltage of $3V_M$ will appear at the output terminals of the circuit. The voltage rating of C_1 and C_3 must be greater than V_M, and the rating of C_2 must be greater than $2V_M$. The diodes should be able to block at least twice the maximum peak value of the input supply voltage. The ripple frequency of the output is twice that of the input. The output characteristics for the full-wave tripler are shown in Figure 8.

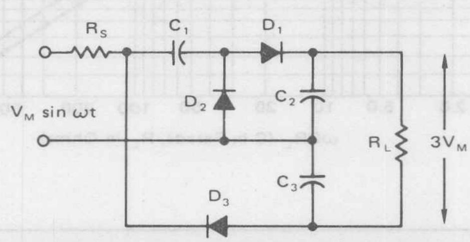


Figure 7 – Full-Wave Voltage Tripler Circuit

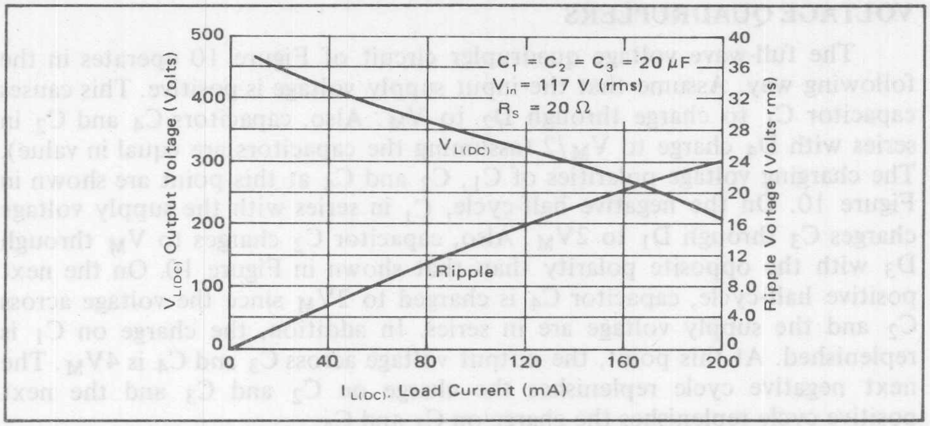


Figure 8 — Output Characteristics for the Full-Wave Voltage Tripler Circuit of Figure 7

The cascade principle may be extended to obtain a voltage tripler as shown in Figure 9. The operation of the cascade voltage tripler is quite similar to that of the cascade voltage doubler circuit. The voltage rating of C_1 should be greater than V_M and the voltage ratings of C_2 and C_3 should be greater than $2V_M$. The peak inverse voltage ratings of the diodes should also exceed $2V_M$. The ripple frequency of the output voltage will be the same as the frequency of the applied voltage.

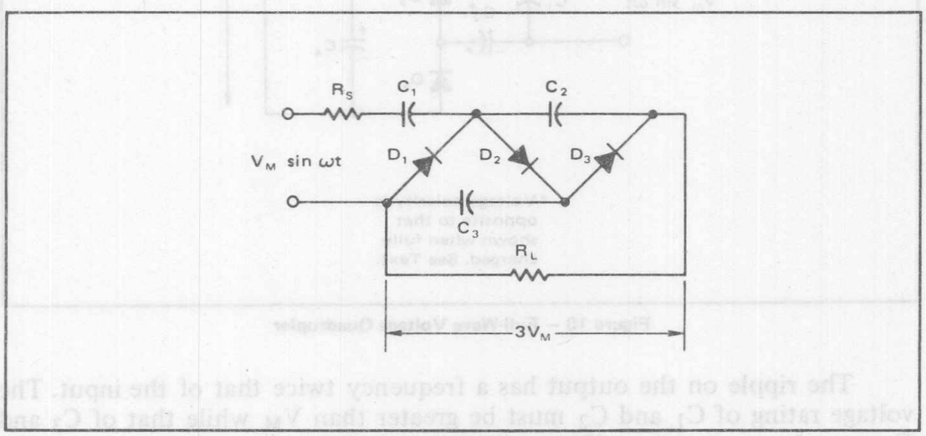


Figure 9 — Cascade (Half-Wave) Voltage Tripler

As might be anticipated, the regulation and ripple of the cascade voltage tripler is inferior to that of the full-wave voltage tripler. For a comparison of the two circuits, refer to Table 2.

Circuit Configuration	R_L Ohms	$V_{L(DC)}$ Volts	$I_{L(DC)}$ mA	r_F	R_L Ohms	$V_{L(DC)}$ Volts	$I_{L(DC)}$ mA	r_F %
Full-Wave	5.0k	385	77	2.4	1.5k	255	170	8.0
Half-Wave	5.0k	328	66	28.0	1.5k	170	112	37.0

Table 2. Voltage Tripling Circuit Characteristics

VOLTAGE QUADRUPLERS

The full-wave voltage quadrupler circuit of Figure 10 operates in the following way. Assume that the input supply voltage is positive. This causes capacitor C_1 to charge through D_2 to V_M. Also, capacitors C_4 and C_2 in series with D_4 charge to $V_M/2$ (assuming the capacitors are equal in value). The charging voltage polarities of C_1, C_2 and C_4 at this point are shown in Figure 10. On the negative half-cycle, C_1 in series with the supply voltage charges C_3 through D_1 to $2V_M$. Also, capacitor C_2 charges to V_M through D_3 with the opposite polarity than that shown in Figure 10. On the next positive half-cycle, capacitor C_4 is charged to $2V_M$ since the voltage across C_2 and the supply voltage are in series. In addition, the charge on C_1 is replenished. At this point, the output voltage across C_3 and C_4 is $4V_M$. The next negative cycle replenishes the charge on C_2 and C_3 and the next positive cycle replenishes the charge on C_1 and C_4.

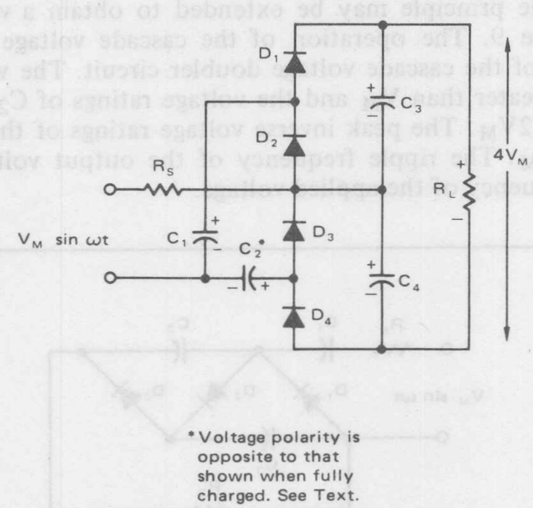


Figure 10 – Full-Wave Voltage Quadrupler

The ripple on the output has a frequency twice that of the input. The voltage rating of C_1 and C_2 must be greater than V_M while that of C_3 and C_4 must be greater than $2V_M$. All of the diodes must have a voltage rating greater than $2V_M$. Output characteristics are shown in Figure 11.

The cascade half-wave voltage quadrupling circuit is shown in Figure 12. The operation of this circuit is basically the same as the other cascade networks. The capacitance of C_1 should be high and its voltage rated above V_M while the remaining capacitors and the diodes should be rated above $2V_M$. The ripple frequency of the output is the same as that of the supply.

The regulation of the half-wave voltage quadrupler is inferior to the full-wave as might be expected. (Compare Figure 11 to Figure 13.) To improve regulation, the values of capacitors C_1 and C_2 are increased. To illustrate this improvement, the output characteristics of the circuit of Figure 12 were obtained when all capacitors equal 20μF and 40μF. The results are shown in Figure 13.

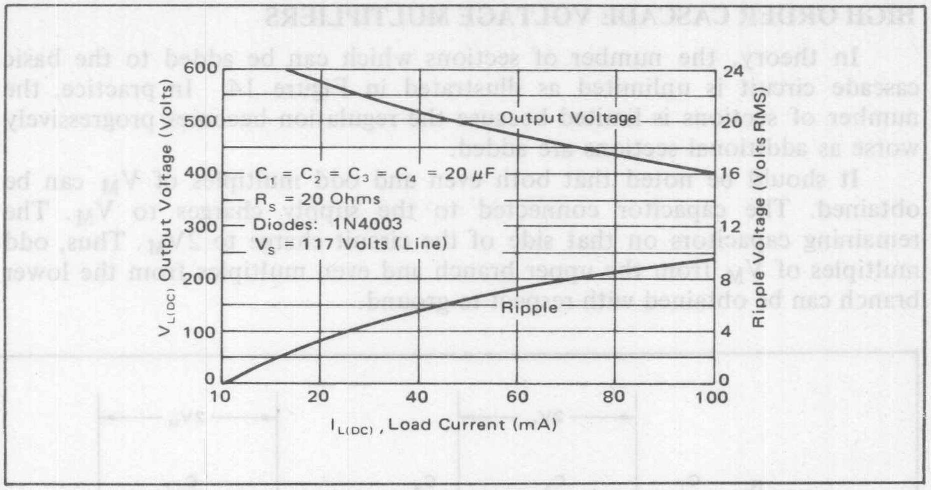


Figure 11 – Output Characteristics of a Full-Wave Voltage Quadrupler Circuit

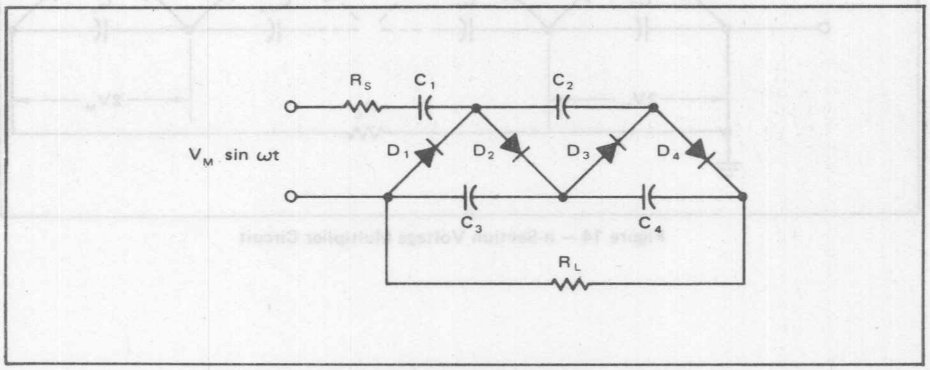


Figure 12 – Cascade (Half-Wave) Voltage Quadrupler Circuit

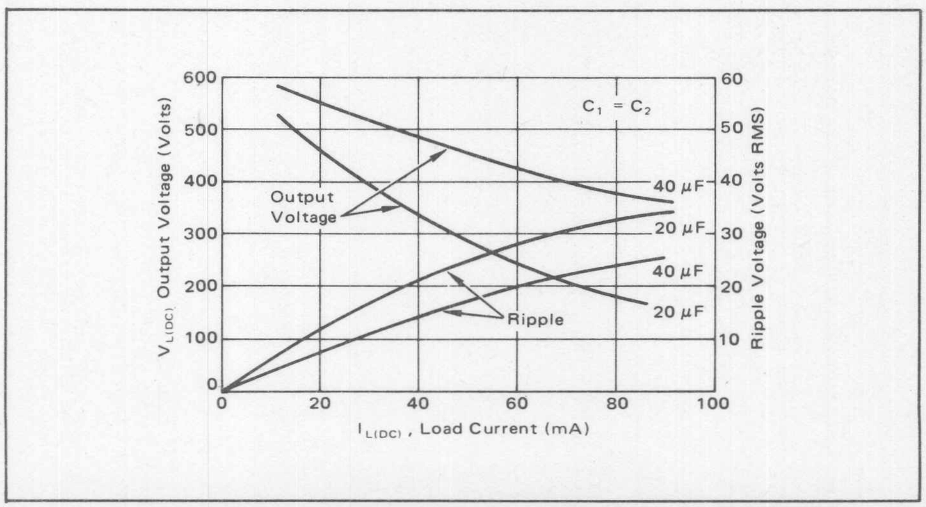


Figure 13 – Output Characteristics of the Half-Wave Voltage Quadrupler Circuit

HIGH ORDER CASCADE VOLTAGE MULTIPLIERS

In theory, the number of sections which can be added to the basic cascade circuit is unlimited as illustrated in Figure 14. In practice, the number of sections is limited because the regulation becomes progressively worse as additional sections are added.

It should be noted that both even and odd multiples of V_M can be obtained. The capacitor connected to the supply charges to V_M. The remaining capacitors on that side of the circuit charge to $2V_M$. Thus, odd multiples of V_M from the upper branch and even multiples from the lower branch can be obtained with respect to ground.

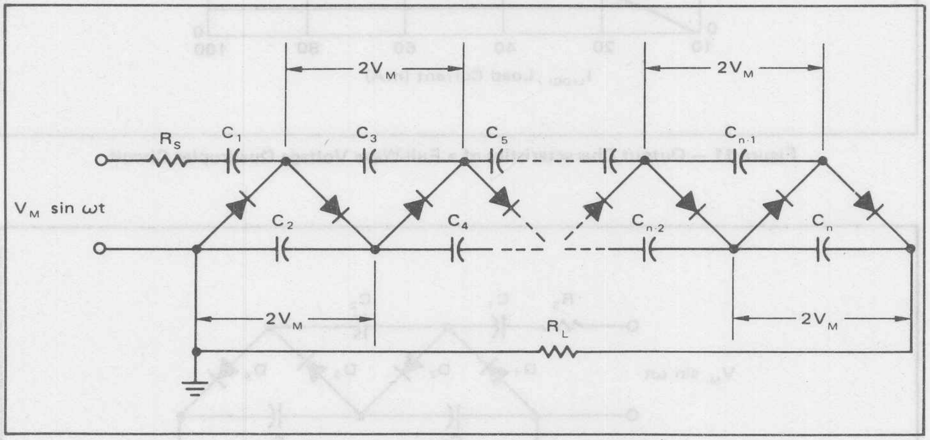


Figure 14 — n-Section Voltage Multiplier Circuit

CHAPTER 8: CIRCUITS USING DIODES

Since rectifiers are basically diodes with high surge current and high reverse voltage ratings, they provide more rugged alternatives to small signal diodes in many circuits where the latter would ordinarily be used. Rectifiers also permit certain functions to be carried out at power levels beyond the capability of their small signal counterparts. Some of the most commonly used circuits are presented in this chapter. The free-wheeling diode is an important application of rectifiers and is consequently covered in greater detail than are the others mentioned.

FREE-WHEELING DIODE CIRCUITS

The silicon diode can be used quite effectively as a free-wheeling diode to suppress arcing in switches and relay contacts. By suppressing arcs, switching contacts will have longer mechanical life and require less maintenance. A free-wheeling diode or some type of voltage clamp is almost a necessity for over voltage protection of semiconductors having an inductive load.

To understand the problem associated with an inductive load, consider the simple switching circuit shown in Figure 1. The circuit contains a relay coil of inductance L in series with switch S, battery V_S, and resistance R_L (which represents the relay coil resistance). With the switch closed, the battery applies voltage across the relay causing a magnetic field to develop in the coil as the current increases. The current in the circuit is given by the following equation:

$$i = \frac{V_S}{R_L}\left(1 - e^{-tR_L/L}\right) \tag{1}$$

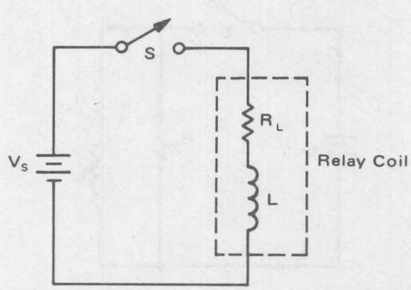


Figure 1 — Basic Switching Circuit With Inductive Load

time constant.

When the switch is opened, the current in the circuit has to decrease to zero in the amount of time required to open the switch. The voltage across the inductor is given by Equation 2.

$$v_L = L\frac{di}{dt} \qquad (2)$$

The significance of Equation 2 may be appreciated by an example: Assume

$L = 0.1$ Henry,

$V_S = 10$ volts,

$R_L = 20$ ohms.

∴ The steady state value of current is $10V/20\Omega = 0.5A$.

Assuming that the switch turns off in 0.1 μs and that during this time interval the current linearly decreases to zero, the maximum voltage developed across the coil can now be determined. $di/dt = \Delta i/\Delta t = 0.5/(0.1) = 5V/\mu s$ and from Equation 2, $\Delta v_L = L\,\Delta i/\Delta t = (0.1)(5)/10^{-6} = 500{,}000$ volts. The result is an arc if S is a mechanical contact or probably a shorted element if S is a semiconductor switch. It is not possible to predict the time for the current to decay when arcing occurs since it is dependent upon the characteristics of the arc. However, if a low value resistor (R_S) is placed across the coil as in Figure 2, arcing will not occur, and the decay time of current is given by:

$$i = \frac{V}{R} e^{-tR/L} \qquad (3)$$

where R is the total resistance in the loop, i.e. $R_S + R_L$.

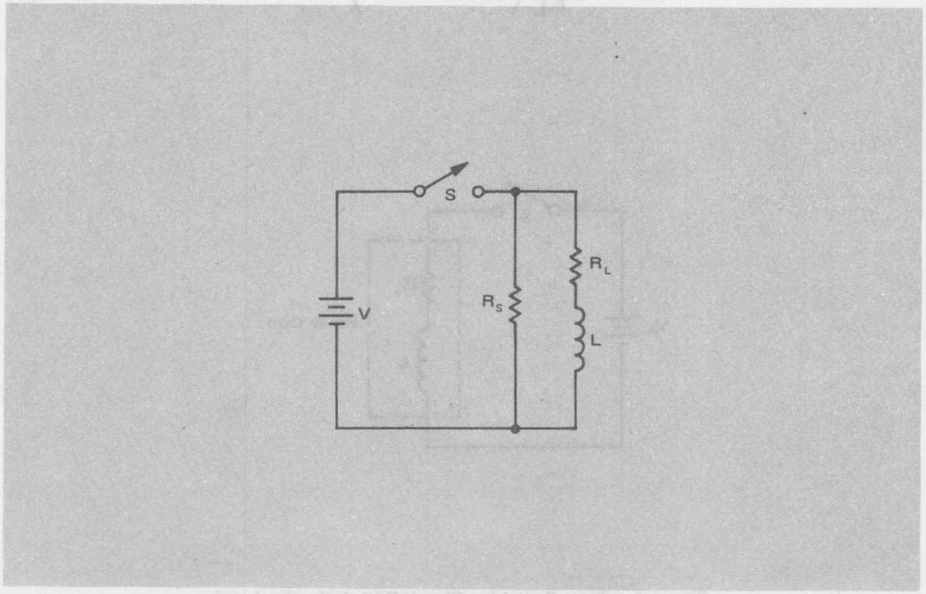


Figure 2 – Transient Voltage Suppression by Use of a Resistor

The peak voltage generated is now attenuated at the switch contact by the ratio $R_S/(R_S + R_L)$. When the switch is opened, R_S should be small for maximum attenuation of the inductive voltage "kick". However, a small value causes a large current through R_S at switch closure. Use of a rectifier as in Figure 3a provides the ideal solution. No power loss results when the switch is closed; when it is opened little inductive kick results from the circuit because the diode resistance (R_S) is very low. The amount of the voltage spike can be traded for decay time by using an additional physical resistance R_S in series with the diode as shown by Figure 3b.

Besides serving as part of an attenuation network, R_S also reduces di/dt by providing a path for the current in the inductor to go when the switch is opened. The voltage v_S across R_S (neglecting the diode drop) can be found by taking the derivative of Equation 3 and substituting into Equation 2. The result is

$$v_S = V\left(1 + \frac{R_S}{R_L}\right) e^{-tR/L} \tag{4}$$

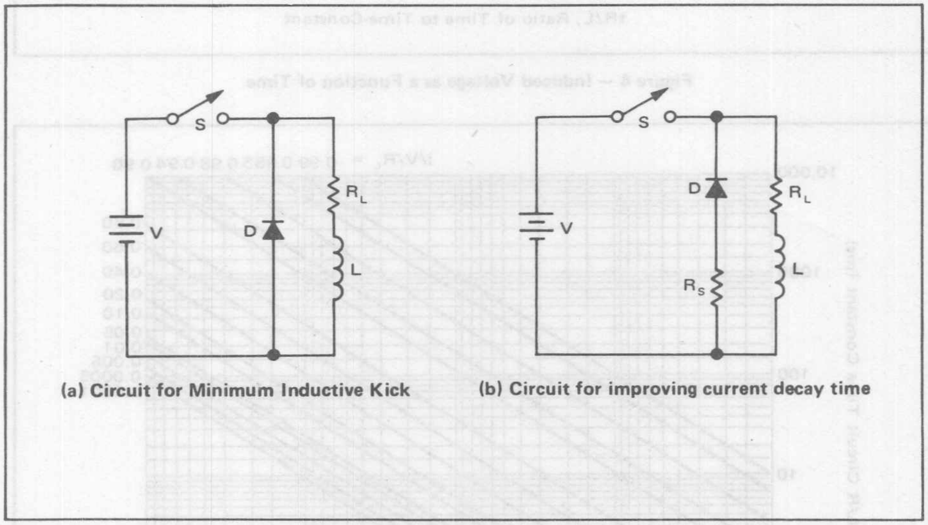


Figure 3 – Free-Wheeling Diode Circuits

The selection of the rectifier for a given application will depend primarily on the peak value of the current through the device which is equal to the steady-state current through the relay coil. For example, if the inductive load carries 10 A at steady state, and operation of the switch is such that the current and voltage decay to zero after each switching operation, the rectifier selected should have a peak repetitive current rating of 10 A. The peak inverse rating of the device must be greater than the supply voltage plus the allowable inductive "kick" voltage across R_S. Another important characteristic is the diodes forward recovery time, since R_S is infinite until the diode can turn on. In this respect, the Schottky barrier rectifier is unexcelled.

Figure 4 illustrates the relationship of v_S to the R_S/R_L ratio and the time constant of the circuit from Equation 4. As an additional circuit aid, Figure 5 shows the time for the current to decay to a given fraction of the initial coil current, as a function of the circuit time constant. It is a plot of Equation 3.

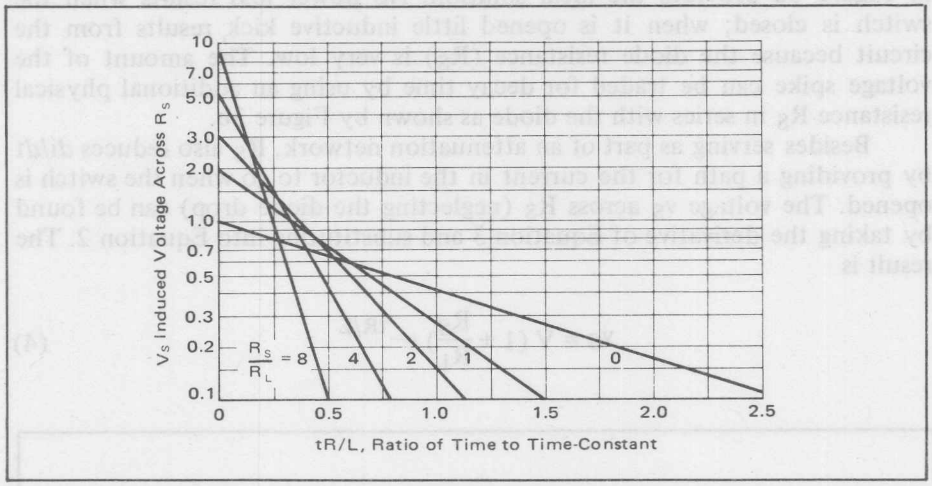


Figure 4 — Induced Voltage as a Function of Time

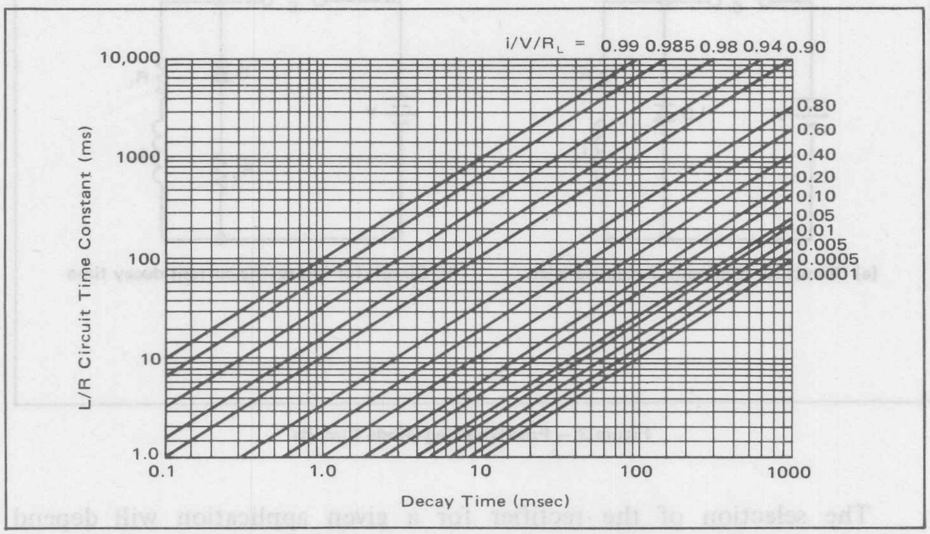


Figure 5 — Decay Time as a Function of the Circuit Time Constant and the Fraction of Initial Current.

The following example illustrates the use of the curves:

Circuit Constants	*Circuit Requirements*
L = 0.1 H	Time to drop out = 1.0 ms
R_L = 20 Ω	Find R_S and $v_{S(peak)}$
V = 12 V	
I = 200 mA for relay dropout	

Solution:

To use Figure 5, first find

$$\frac{i}{V/R_L} = \frac{0.2}{(12)/20} = 0.33.$$

Read L/R = 0.8 ms (by interpolation note that the slope of the curve is unity).

$$\therefore R = R_S + R_L = 0.1/(0.8)(10^{-3}) = 125\ \Omega,$$

To find $v_{S(peak)}$ use Equation 4 at t = 0.

$$v_S = V_S\left(1 + \frac{R_S}{R_L}\right) = 12\left(1 + \frac{105}{20}\right) = 75 \text{ volts.}$$

VOLTAGE REGULATORS

Many low-voltage applications often require regulated outputs. Inexpensive regulator circuits usually employ rectifiers to obtain a regulated output. In the circuit of Figure 6, a string of rectifiers is used instead of the more usual zener diode. In very low voltage applications, the rectifier has a sharper knee than a zener diode; however, its temperature coefficient is higher.

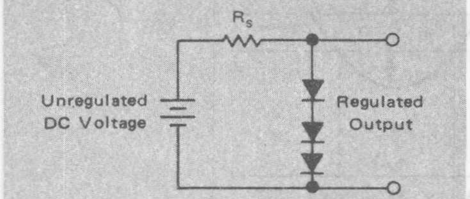


Figure 6 – Typical Diode Regulator

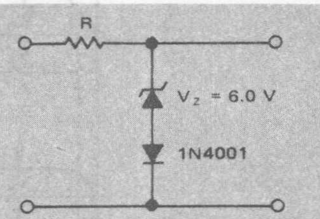


Figure 7 – Use of a Rectifier for Zener Temperature Compensation

Standard diodes may be used to provide a measure of temperature compensation for zener diodes. Figure 7 illustrates the technique. For higher values of zener voltages, additional rectifier compensating diodes must be used in series. Table 1 shows the number of diodes required for various zener voltages to obtain an approximate zero temperature coefficient reference. By varying the current through the string, the overall temperature coefficient may be adjusted. This is possible because the rectifier diode temperature coefficient is a function of the forward current, while the zener diode temperature coefficient is relatively constant.

Number of Diodes	Approximate Zener Voltage (Volts)
1	6.0
2	7.5
3	9.1
4	11.0
5	13.0

Approximate value of zener voltage which may be compensated by discrete numbers of 1N4001 diodes at $I_F \approx$ 1mA

Table 1

WAVEFORM CLIPPERS

In clipping, a portion of a wave is flattened off or limited to some arbitrary level, irrespective of the amplitude of the original signal. Clippers may be conveniently classified as peak clippers, base clippers, or slicers, according to the way in which they operate on a wave.

A peak clipper, also called a peak limiter, operates in such a manner as to prevent the positive (or negative) amplitude of the wave from ever exceeding a value set by the clipper. A simple example of such a clipper is illustrated in Figure 8.

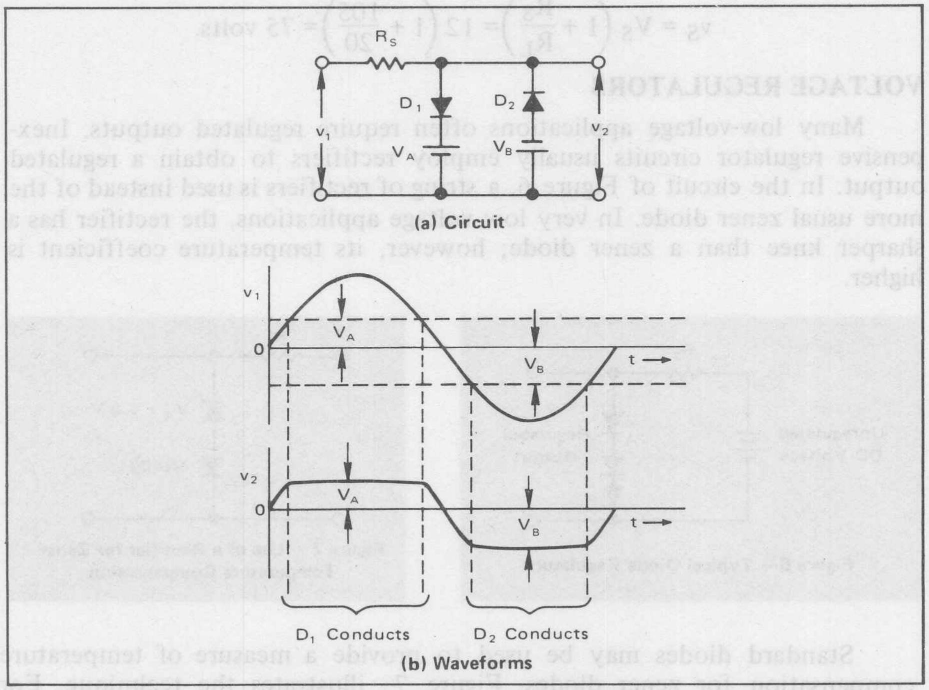
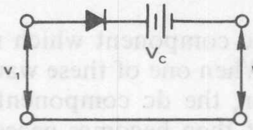


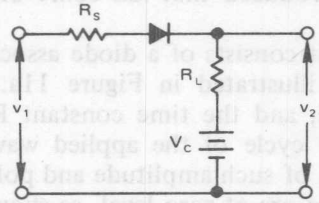
Figure 8 — Diode Clipping Circuit with Waveforms Involved When Clipping a Sine Wave.

When the instantaneous value of the input voltage wave lies between V_A and $-V_B$ neither of the diodes conduct, and the input wave is transmitted directly to the output terminals without change. On the other hand, when the input voltage is more positive than V_A, diode D_1 will conduct and thus prevent the output voltage from rising appreciably above V_A. Similarly, when the input voltage becomes more negative than $-V_B$, diode D_2 will conduct and clip the negative peaks of the output voltage at a level approximating $-V_B$. For the diode clippers D_1 and D_2 to be effective, the series resistance R_S must be considerably greater than the forward resistance of the diodes.

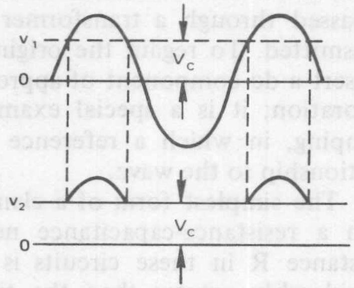
Circumstances sometimes arise when it is desired to reduce to zero all amplitudes of a wave that are less than some minimum value. Base clipping of this type can be obtained with the circuits illustrated in Figure 9. The diode is reverse biased to a voltage V_C corresponding to the level of base clipping desired, so that no output current flows until the applied voltage exceeds this value.



(a) Base Waveform Clipper. A zener diode in parallel with a large capacitor may be used for V_C for repetitive input waves.



(b) Base Waveform Clipper With Bias supply returned to ground. For good clipping action R_S must be much larger than R_L.



(c) Waveforms illustrating the clipping of a Sine Wave.

Figure 9 — Base Waveform Clippers and Waveforms.

Clippers may be combined in various ways. A particularly important combination is illustrated in Figure 10. Here the combination of diode D_1, resistance R_S, and bias V_A serves as a peak clipper, while diode D_2 in association with bias V_B simultaneously functions as a base clipper. The result is that all input voltages in excess of V_A are clipped in such a manner as to produce an output voltage having a value $V_A - V_B$, while all values of input voltage that are less than V_B are reduced to zero amplitude in the output. An arrangement of this type is termed a slicer, since the output wave can be regarded as consisting of a slice of the input waveform.

In these circuits, the diode and battery potentials may be reversed in order to have clipping occur above or below any point on a waveform.

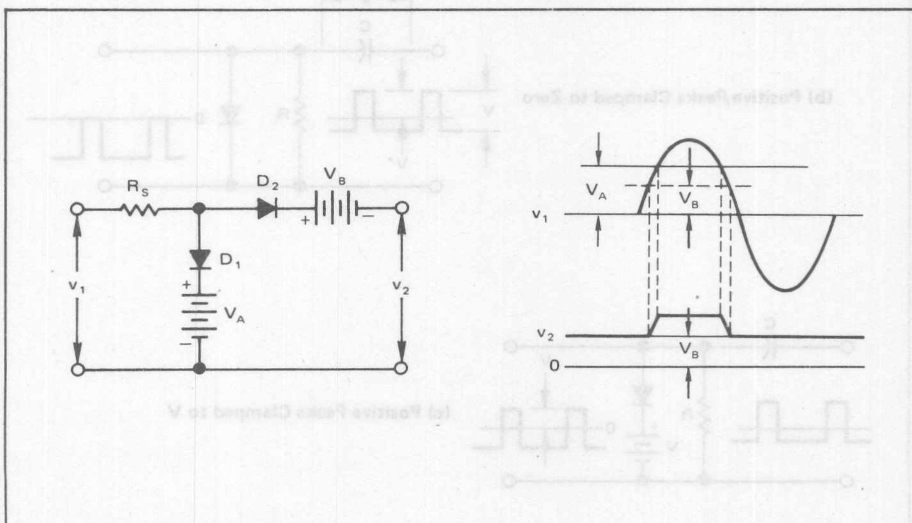


Figure 10 — A Slicer Circuit with Waveforms Showing the Behavior for a Sine Wave Input.

CLAMPING CIRCUITS – DC RESTORATION

Many asymmetrical waveforms possess a dc component which remains fixed, i.e., is not a function of the waveform. When one of these waveforms is passed through a transformer or a capacitor, the dc component is not transmitted. To regain the original waveform it then becomes necessary to reinsert a dc component of appropriate amplitude. This process is termed dc restoration; it is a special example of a more general process known as clamping, in which a reference level is introduced that has some desired relationship to the wave.

The simplest form of a clamping circuit consists of a diode associated with a resistance-capacitance network, as illustrated in Figure 11a. The resistance R in these circuits is quite large, and the time constant RC is considerably greater than the time of one cycle of the applied wave. If circuits are used that insert a dc component of such amplitude and polarity that the negative peaks of the original wave are at zero level, as shown in Figure 11a, then it is said that the negative peaks of this wave are clamped to zero. The same wave with its positive peaks clamped to zero volts and to +V volts is shown in parts (b) and (c) respectively.

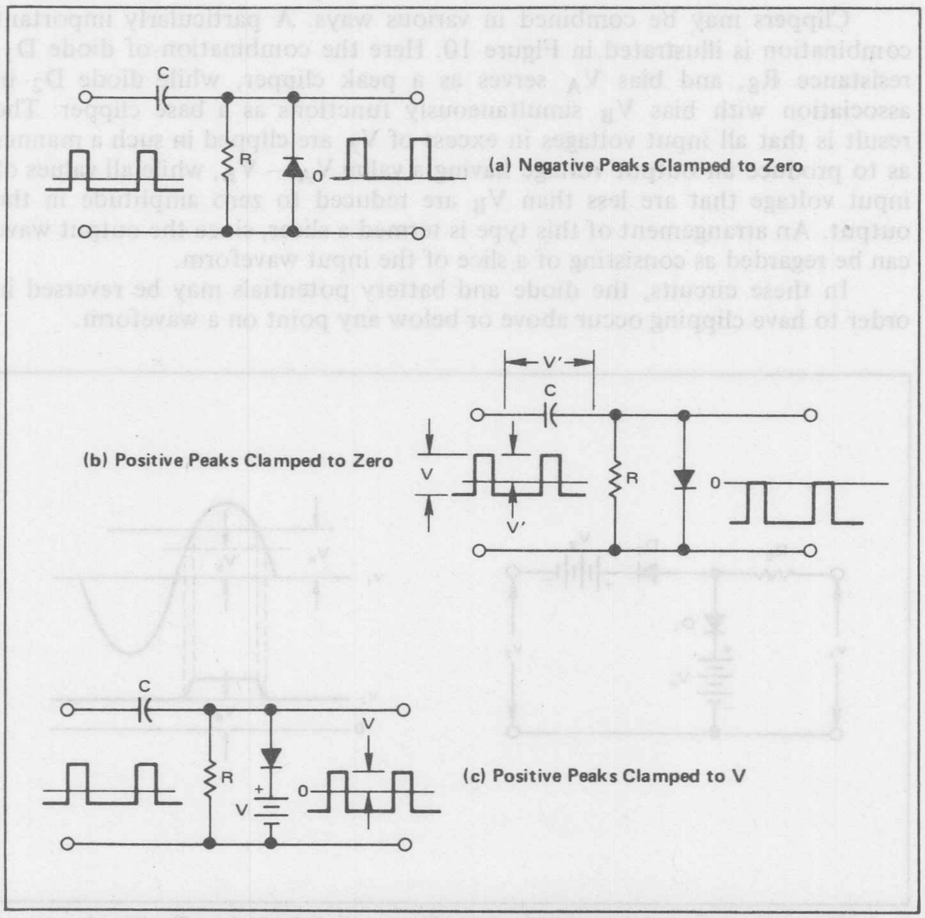


Figure 11 – Clamping Circuits and Waveforms.

The detailed action of the diode clamp of Figure 11b can be understood by considering Figure 12. If RC is so large that it can be considered as infinite, then the diode charges capacitance C to a voltage V′ that just barely prevents the output voltage V_O from going positive; thus, V′ is the reinserted dc voltage. However, if RC is high but not infinite, then some of the charge on the capacitor leaks off during the time interval $t_3 - t_2$. This causes the output wave to decay with a time constant RC during the time interval $t_3 - t_2$; however, if RC is very much greater than the time $t_3 - t_2$, the change ΔV_0 in the amplitude of the output voltage will be small. At t_3 the voltage at the output terminals increases suddenly in amplitude by the peak-to-peak amplitude V of the applied wave and makes the output voltage go ΔV_0 volts positive at time t_3. This causes current to flow into the capacitor to replace the charge that leaked off during the previous period, as shown. The time constant associated with this current flow corresponds to C being charged through the diode and source resistance.

The proper value for the time constant RC is a compromise between two conflicting requirements. The larger this time constant, the less will be the variation ΔV_0 of the clamping voltage during the cycle, and, hence, the smaller will be the positive spike at t_1 and t_3. On the other hand, the larger the value RC, the more slowly is the clamping voltage able to adjust itself to reductions in amplitude of the wave that is to be clamped.

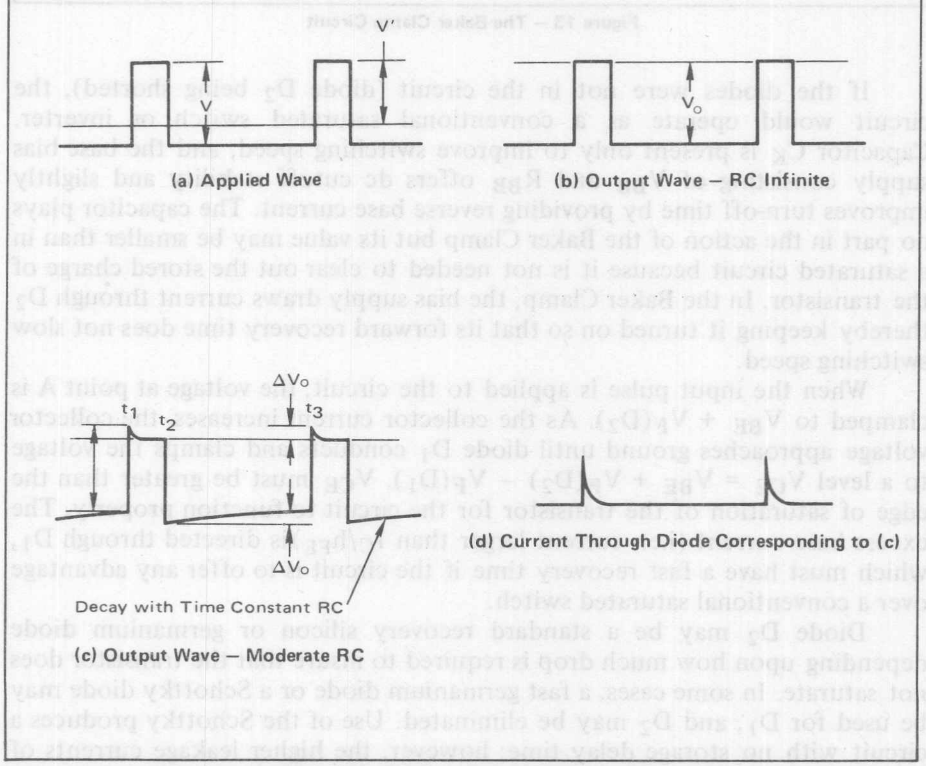


Figure 12 – Detailed Waveforms of the Clamping Circuit of Figure 9b.

THE BAKER CLAMP

When transistors are operated as a saturated switch, a turn-off delay (called storage time) results from the presence of the stored charge caused by the excess base current required to drive the transistor into saturation. One method of eliminating storage time employs diodes in a feedback arrangement as shown in Figure 13. The voltage drop across the diodes is such that the collector-base diode is not allowed to become forward biased, i.e., the transistor is not operated in the saturation region.

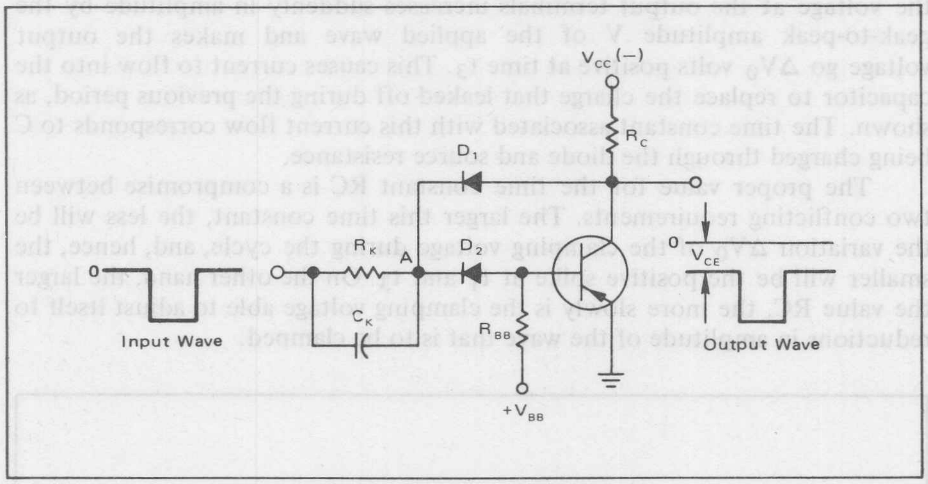


Figure 13 – The Baker Clamp Circuit

If the diodes were not in the circuit (diode D_2 being shorted), the circuit would operate as a conventional saturated switch or inverter. Capacitor C_K is present only to improve switching speed, and the base bias supply consisting of V_{BB} and R_{BB} offers dc cutoff stability and slightly improves turn-off time by providing reverse base current. The capacitor plays no part in the action of the Baker Clamp but its value may be smaller than in a saturated circuit because it is not needed to clear out the stored charge of the transistor. In the Baker Clamp, the bias supply draws current through D_2 thereby keeping it turned on so that its forward recovery time does not slow switching speed.

When the input pulse is applied to the circuit, the voltage at point A is clamped to $V_{BE} + V_F(D_2)$. As the collector current increases, the collector voltage approaches ground until diode D_1 conducts and clamps the voltage to a level $V_{CE} = V_{BE} + V_F(D_2) - V_F(D_1)$. V_{CE} must be greater than the edge of saturation of the transistor for the circuit to function properly. The excess base current (i.e., current larger than I_C/h_{FE})is directed through D_1, which must have a fast recovery time if the circuit is to offer any advantage over a conventional saturated switch.

Diode D_2 may be a standard recovery silicon or germanium diode depending upon how much drop is required to insure that the transistor does not saturate. In some cases, a fast germanium diode or a Schottky diode may be used for D_1, and D_2 may be eliminated. Use of the Schottky produces a circuit with no storage delay time; however, the higher leakage currents of Schottky diodes must be considered in the dc design of the circuit.

SCR CIRCUITS

Rectifiers also provide an excellent means of stabilizing the reverse bias on the gate-to-cathode of silicon controlled rectifiers, as illustrated by Figure 14. Reverse bias improves silicon controlled rectifier characteristics, and the diode insures that the reverse gate voltage will not exceed the forward drop of the diode.

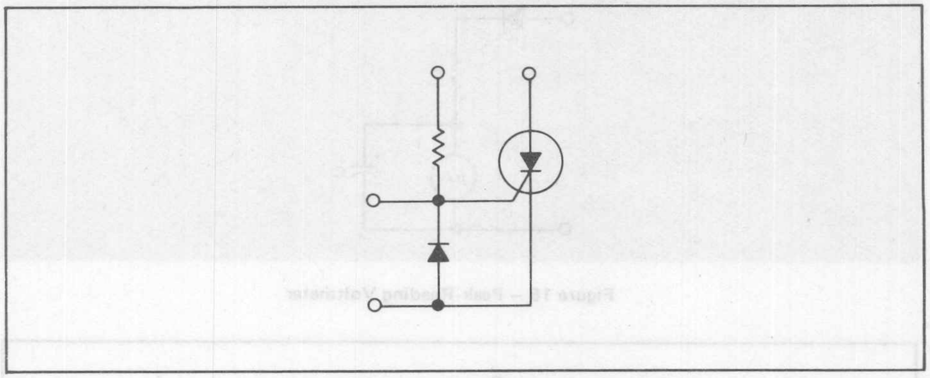
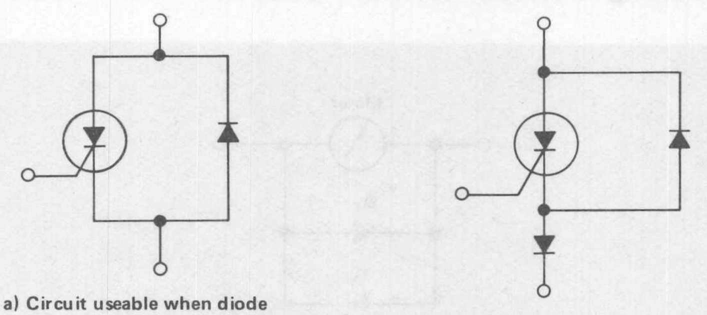


Figure 14 – Rectifier Stabilizes Reverse Bias for SCR

It is often necessary to limit the reverse voltage impressed upon a silicon controlled rectifier to a value less than the ac input voltage. The rectifier circuits shown in Figure 15 are designed to accomplish this purpose. The diode in Figure 15a carries the same amount of current as the silicon controlled rectifier, which may be unacceptable in some applications. The circuit of Figure 15b has approximately the same reverse voltage reduction properties as the circuit of Figure 15a, but the rectifier doesn't have to handle as much current. This shunt diode may be a high-voltage, low-current type. The series-diode must handle high current. The circuit of Figure 15b is often used in high-reliability systems.



a) Circuit useable when diode conduction is permissible

b) Circuit which conducts unilaterally.

Figure 15 – Rectifier.Used to Lower Impressed Voltage on SCR

MEASUREMENT AND INSTRUMENT CIRCUITS

Rectifiers find many useful applications in measurement circuits. An example is Figure 16, the peak reading voltmeter. This circuit may be used to measure the peak voltage of any waveform with sufficient pulse repetition frequency to keep the shunt capacitor charged. Schottky diodes (or the circuit of Figure 17) should be used if the input signal level is low.

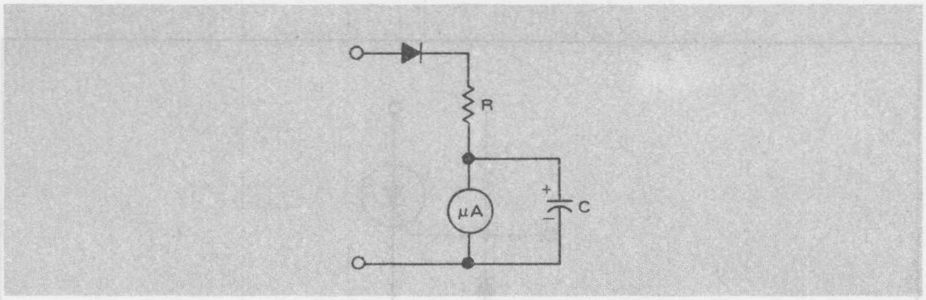


Figure 16 – Peak-Reading Voltmeter

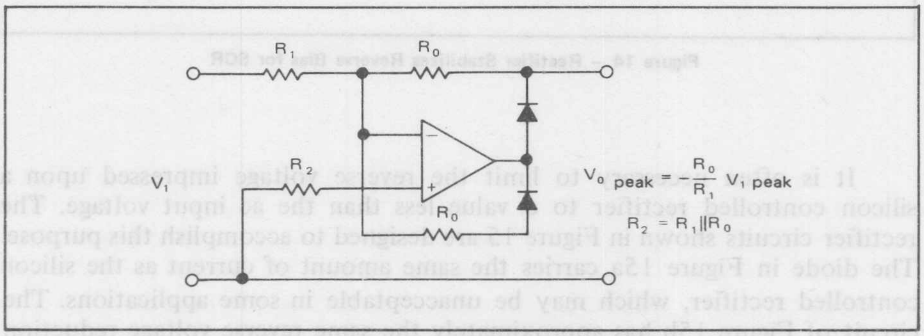


Figure 17 – The forward voltage drop of the rectifier is reduced by the open loop voltage gain of the operational amplifier

Figure 18 shows a dc meter protection circuit designed to limit the voltage across the meter to a value not exceeding the forward voltage of the diodes. Diode D_1 should be a Schottky diode to keep the reverse voltage to a few tenths of a volt, while diode D_2 will have to be a standard rectifier to avoid introducing errors into the measurement as a result of diode current.

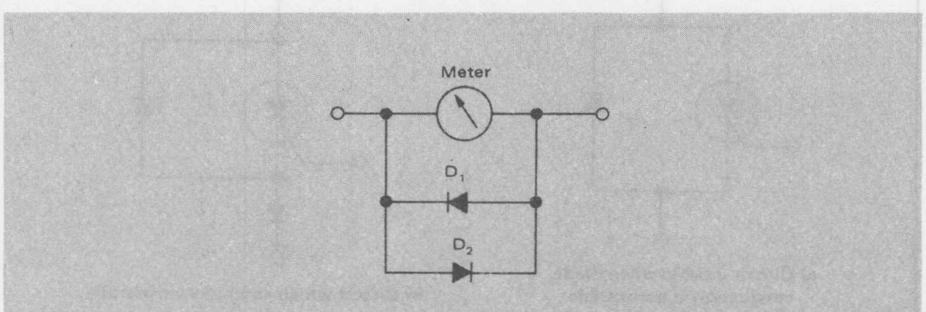


Figure 18 – DC Meter Protection Circuit

Triangular waves are easily converted to sinusoids by using the method shown in Figure 19. Sinusoids of less than 1 percent total harmonic distortion can be obtained if diodes are carefully matched and the value of R and the input amplitude are properly chosen.

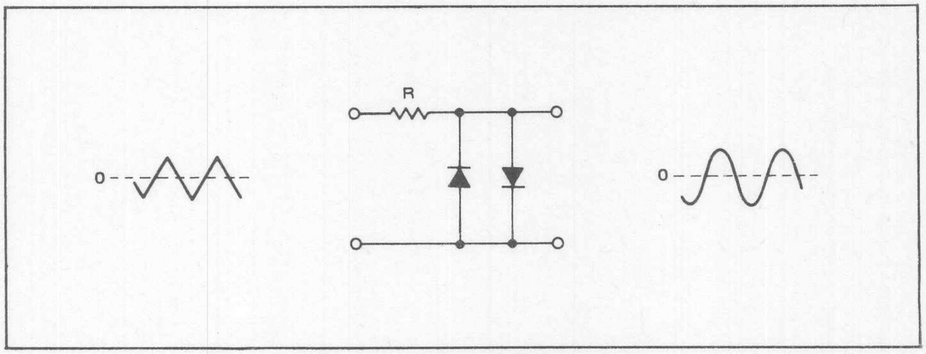


Figure 19 – Sine wave Generation

MISCELLANEOUS APPLICATIONS

A diode used in series with power supply leads of dc equipment effectively guards against damage resulting from supply reversal as shown in Figure 20. The Schottky diode is especially useful in this application because of its low forward voltage.

The rectifier is often an ideal device for use as a nonlinear resistor. An example is high level limiting on a telephone receiver as shown in Figure 21.

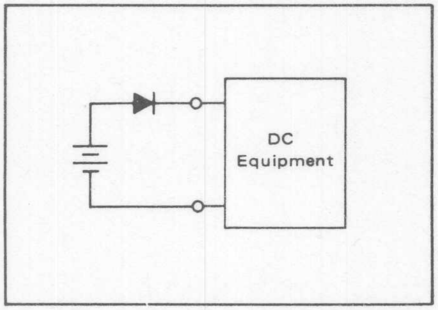


Figure 20 – Polarity Reversal Protection

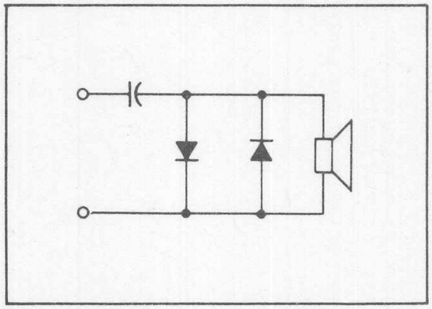


Figure 21 – Rectifier as a Non-Linear Resistor

CHAPTER 9: TRANSIENT PROTECTION OF RECTIFIER DIODES

In order to achieve the high degree of reliability already associated with silicon rectifier diodes, it is imperative to understand the meaning of the ratings and to be aware of a few subtle application differences with respect to selenium and copper-oxide devices.

The ratings are based on the absolute maximum rating system. This means that they apply within a certain defined set of operating, test, or environmental conditions, and that degradation or failure may be caused by a combination of electrical or environmental stresses, any one of which alone could not impair the performance of the device. These ratings are established by extensive tests, including life-tests conducted by the manufacturer, and are typically checked during production by quality control sampling. The duration of the life-test and the required survival rate are determined by the intended application. Where reliability is a key factor for the intended application, the manufacturer should be consulted. The user should be aware that there is no safety factor implied above each maximum rating, although manufacturers generally employ one.

Silicon rectifier diodes utilize monocrystalline cells which have an effective area several thousand times smaller than their selenium or copper-oxide counterparts with equivalent current ratings. Consequently, the smaller thermal mass associated with silicon devices allows the junction temperature to rise and to fall very rapidly during a current surge and remain undetected by an external thermocouple. If during this event the junction temperature exceeds the maximum rated value and rated reverse voltage appears, the device may fail destructively (short) as a result of thermal breakdown. Silicon diodes, however, lend themselves to precise rating techniques so that the exact excursion of the junction temperature during expected overloads can be known and thus held within proper limits through circuit design.

SURGE VOLTAGE PROTECTION

Because of the sensitivity of silicon rectifier diodes to voltage transients in excess of their ratings, a proper circuit design generally requires some built-in means to afford safe operation. Therefore, it is imperative to discuss some of the causes and cures of voltage surges.

Sources of Transients

Transient voltages generally are caused by the following:

1. De-energizing the transformer primary.
2. Energizing the transformer primary.
3. External disturbances caused by lightning or motors, solenoids, relay circuits, etc., which share the same alternating-current source with the rectifier circuit.
4. Alternating-current switching, e.g., SCR phase control circuits.

5. Opening load switch when using an LC filter with high LC ratio.
6. Regenerative types of load.
7. Fuse-blowing when used for isolating defective rectifier diodes which are connected in parallel.
8. Reverse recovery transients of the rectifiers.

Each causes a different degree of voltage oscillation, e.g., some generate up to twice the working peak reverse voltage of the circuit, while others can generate as high as eight or ten times this value. Lightening strikes can cause particularly severe transients on supply lines. A frequently overlooked source is the transient coupled from the line to the secondary of a stepdown transformer through interwinding capacitance when a switch is closed.

Most of the circuit developed transients can be described by the familiar basic relation, $v = L\, di/dt$. Therefore, anything which causes rapid switching of a high current is liable to generate a troublesome transient. This problem is explored in some detail in Chapter 8 under the section "Free-Wheeling Diodes."

Circuit designers often specify a rectifier voltage rating without estimating the extent of the peak reverse voltage transients the rectifier will encounter. A good example is the use of a 200 V rectifier in a half-wave power supply circuit having an rms input voltage of 115 V. Superficially, there seems to be plenty of pad in the reverse voltage rating of 200 V. However, with a possible high line voltage of 130 V (rms) the peak voltage the rectifier will see is 182 V. Any inductance in the circuit or motors nearby could cause an additional voltage spike to be superimposed on that of the peak sine wave. In fact, it is not uncommon to find line voltage spikes on the order of 600 to 700 volts originating from a small drill motor.

Detection of Transients

The best method to use to detect transients is to employ a high-speed oscilloscope having a frequency response to at least 40 MHz. Peak-reading voltmeters may also be used with a lesser degree of certainty because they may not accurately record short transients. They are most conventient for the detection of ac line transients which may occur randomly throughout the day.

When using an oscilloscope, it is important to insure that it does not introduce errors into the test set-up. Battery operated scopes have a decided advantage as they can be floated above ground without introducing coupling from the line into the circuit. Various conditions of circuit operation should be checked in order to find the worst transients; they may not necessarily occur under the obvious conditions of high input voltage and maximum load current. Rectifiers with the highest available voltage capability which meet the forward current rating should be used in the prototype, so that the rectifiers do not limit the voltage transient.

Suppression of Voltage Transients

The best method of suppressing a transient is to go to its source and try to change operating conditions, lead dress, placement of components, or

shielding. After all reasonable means of reducing transients has been exhausted, suitable suppression circuits should be examined. These vary from simple RC or LC L-section filters to more complex circuits using voltage clipping devices or SCRs to remove the transient or shutdown the circuit should an overload occur. The basic technique is to use some component (capacitor, zener clipper, etc.) to absorb the surge across the system and another component (resistor or inductor), in series with the system to limit the surge current. Laboratory tests are always required to determine the effectiveness of the suppression techniques.

Voltage transient suppressors can be quite effective. Table 1 summarizes the various types and gives some typical characteristics of each. Spark gaps and varistors have a tremendous energy absorption ability but allow a higher overshoot voltage to occur than does a zener diode. The zener is also available in tightly controlled voltage ranges. Following are circuits which show methods of suppressing voltage transients by using filters and transient suppressors.

The first set of schematics shown in Figure 1 utilizes a capacitor as an integrator in a simple RC or LC L-section filter. The line operated half-wave supply shown in part (a) uses a capacitor before the rectifier to provide transient protection. In this circuit, transient voltage protection is essential as the line impedance is low, and often low line impedance is desired to make the source resistance R_S small for high efficiency and good filtering action. However, R_S should be large for reliable operation; when it must be small, a series inductance is recommended to help limit and absorb transients.

Transformers introduce other complicating factors. Filters are shown on both sides of the transformer in Figures 1b and 1c, but in many cases protection is satisfactory if used on only one side. In the case of a step-up transformer, primary side protection has an advantage in that the transient is not stepped-up by the transformer; however, secondary side protection permits the leakage inductance and the resistance of the secondary to be the current limiting elements of the filter. Step-down transformers generally require secondary filtering to suppress the transient fed through the interwinding capacitance when a switch is closed to apply the input voltage.

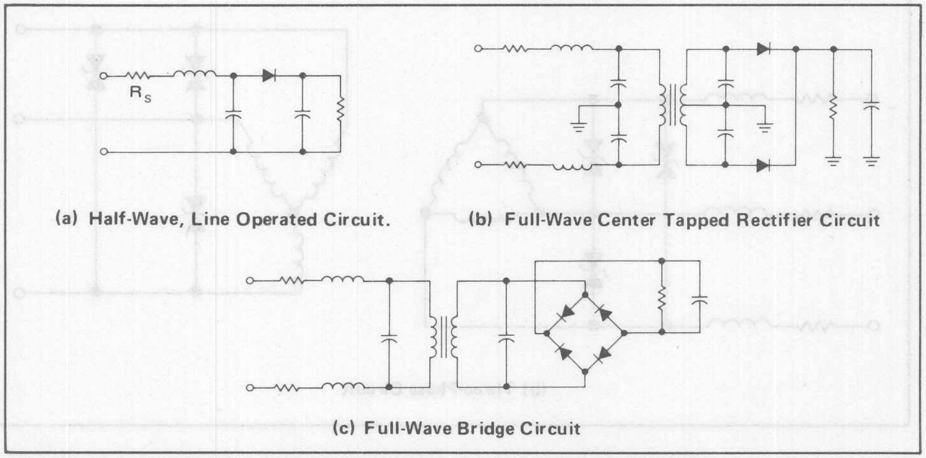


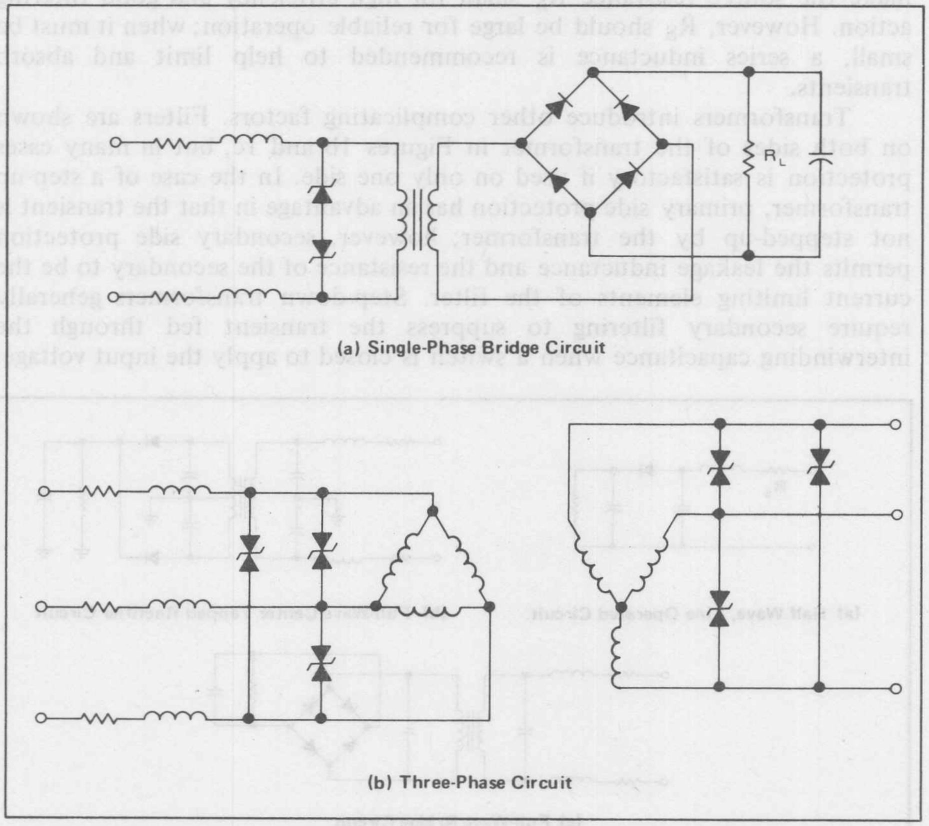
Figure 1 — Transient Suppression using Simple L — Section Filters for High Frequency Transients

Transient Suppressor	Peak Power 1 ms (kW)	Peak Energy 1 ms (joules)	Effective Clamping Ratio At 10 A	Commercial Per Device Voltage Range (V)	Peak Idle Current (mA)	Weight (grams)	Volume (cm^3)
Spark gap (5/16 in OD)	100	100	2.55 (100 V/μs)	90-10 kV	–	1.5	0.6
Varistors Metal Oxide Type (1 in OD)	160	160	2.0	16 – 1,400	1	5	8.0
Selenium Stacks (1 in sq)	9	9	2.3	35 – 700	12	35	20
Zener, 6-cell cluster (1.5 in sq)	7.7	7.7	1.50	10 – 300	0.05	30	24.5
Zener, single (DO-13 case)	1.65	1.65	1.65	1.8 – 300	0.005	1.5	0.5

Adapted from: J. D. Hurnden Jr., et al, "Metal-Oxide Varistor: A New Way to Suppress Transients", ELECTRONICS, October 9, 1972, PP 91 – 95.

Table 1 – Typical Surge Suppressor Characteristics

If the input line has transients of a long time duration, one of the transient suppressor devices is required; it may be substituted for the filter capacitors in the circuits of Figure 1. Figure 2 illustrates examples of using zener diode surge suppressors in two representative applications.



(a) Single-Phase Bridge Circuit

(b) Three-Phase Circuit

Figure 2 – Examples of Transient Suppression Using Zener Diodes as the Energy Absorbing Element Other Active Surge Suppressor Devices Could Be Used As Well

Figure 3 shows two clever types of circuits using diodes and polarized capacitors to clip the voltage spike. In operation, the capacitor charges to the peak of the input waveform; any spikes are clipped by the diode. In part (a), the polarized capacitor is placed across the output terminals of a bridge rectification system. Note the safety precaution of putting a resistor across the capacitor to serve as a bleeder resistor to discharge the capacitor when the circuit is not in use. The circuit of part (b) operates similarly except that two capacitors are required instead of one, and the number of rectifiers is decreased from four to two. Also, since there is a separate capacitor for both the positive and negative spikes, a value of capacitor one half as large may be used with equal effectiveness. The voltage rating of the clipper diode need only exceed twice the peak of the input supply voltage. Since the diodes clip while operating in the forward direction, large surge currents may be handled.

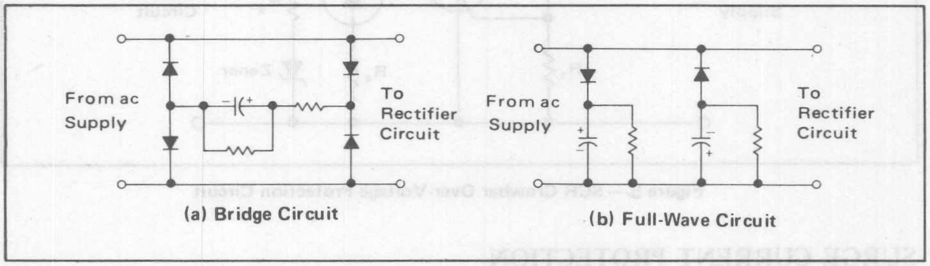


Figure 3 — Transient Suppression Using a Dynamic Peak Limiting Technique

Figure 4 shows various techniques which may be required in tough situations to protect a rectifier diode. The circuits employ the techniques previously discussed, i.e., part (a) uses a capacitor; part (b), a surge suppressor; part (c), a dynamic clipper. Part (d) uses only one zener diode and a small resistor. The idea is to allow the zener to conduct on an over-voltage transient, but the resistor prevents any significant forward current flow through the zener diode.

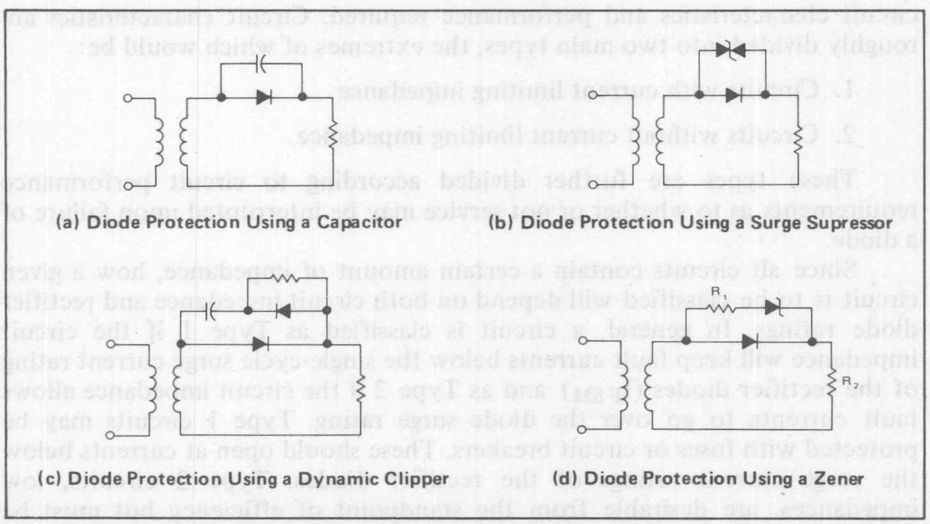


Figure 4 — Various Techniques of Protecting The Rectifier Element Directly

Over-voltage protection by means of a crowbar circuit is shown in Figure 5. As the input voltage increases in a positive direction, the zener voltage threshold is reached causing the zener to conduct current which causes a voltage drop across R_3 that turns SCR_1 on. Resistor R_1 is small so that a large surge current is developed as the SCR shorts or crowbars causing the circuit breaker to open. SCR_2 and its associated components comprise a protection circuit for negative over-voltage.

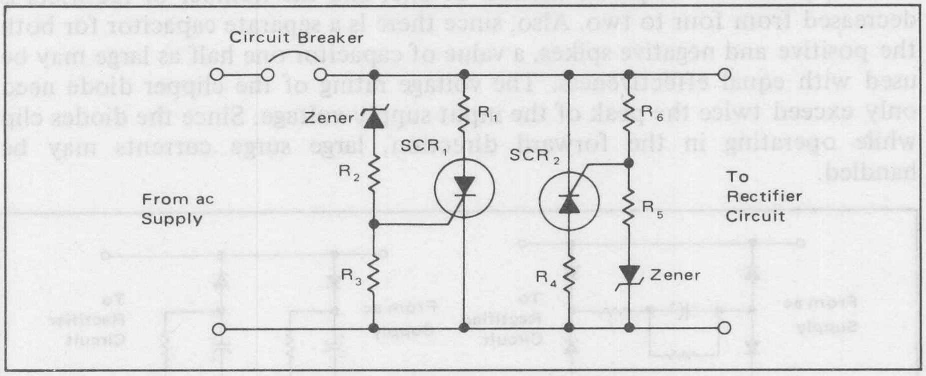


Figure 5 – SCR Crowbar Over-Voltage Protection Circuit

SURGE CURRENT PROTECTION

As previously mentioned, high current surges cause heating of the semiconductor die. If reverse voltage is applied while the rectifier junction is above its rated temperature limit, a short may result from thermal breakdown. Furthermore, even when little or no reverse voltage is present, excessive temperature can weaken the bond of the die to its package causing thermal resistance to increase, thus resulting in a regenerative process leading to destruction. In some cases, excessive current may cause the lead material between the rectifier terminal and the die to fuse.

The type and extent of protection needed will be determined by the circuit characteristics and performance required. Circuit characteristics are roughly divided into two main types, the extremes of which would be:

1. Circuits with current limiting impedance
2. Circuits without current limiting impedance.

These types are further divided according to circuit performance requirements as to whether or not service may be interrupted upon failure of a diode.

Since all circuits contain a certain amount of impedance, how a given circuit is to be classified will depend on both circuit impedance and rectifier diode ratings. In general, a circuit is classified as Type 1 if the circuit impedance will keep fault currents below the single-cycle surge current rating of the rectifier diodes (I_{FSM}) and as Type 2 if the circuit impedance allows fault currents to go over the diode surge rating. Type 1 circuits may be protected with fuses or circuit breakers. These should open at currents below the surge current ratings of the rectifier diodes. Type 2 circuits, low impedances, are desirable from the standpoint of efficiency but must be protected by special fast-acting protective elements.

Causes and Detection of Current Surges

Current surges in rectifier circuits can result from the following factors:

1. Capacitor in-rush
2. Direct current overload
3. Direct current short
4. Failure of a single rectifier diode.

Capacitor in-rush is easy to observe and calculate and is discussed in Chapter 6; the other problems require some heroism in order to observe conditions. Similar precautions regarding the oscilloscope are needed as when detecting voltage transients. Simulation of the fault often may be accomplished by using an SCR as a crowbar; the scope may be triggered by the same signal which fires the SCR.

Fusing Considerations

Basic operation of a fuse is as follows: When a current larger than normal is applied to a fuse, it starts to heat up significantly as temperature is proportional to the square of current. If this current continues for a long enough period of time, the fusible element or link reaches its melting point. As the link melts, voltage builds up across the fusible material which causes arcing. Arcing continues until enough of the link has melted so that the applied voltage can no longer jump the gap. At this time current flow through the fuse stops. This basic operation is shown in Figure 6. The solid line shows the actual fault current due to the limiting action of the fuse and circuit impedance. The dashed line shows the available fault current which would flow without the fuse. As shown, melting of the fuse occurs at point A. Depending on fuse design and the circuit, the current may rise to a peak let-through current as shown at point B and then decay through the impedance of the arcing fuse to zero at point C. The time from point B to point C is the arcing time of the fuse. The melting time and the arcing time together make up the total clearing time of the fuse. Clearing time is often called blowing time.

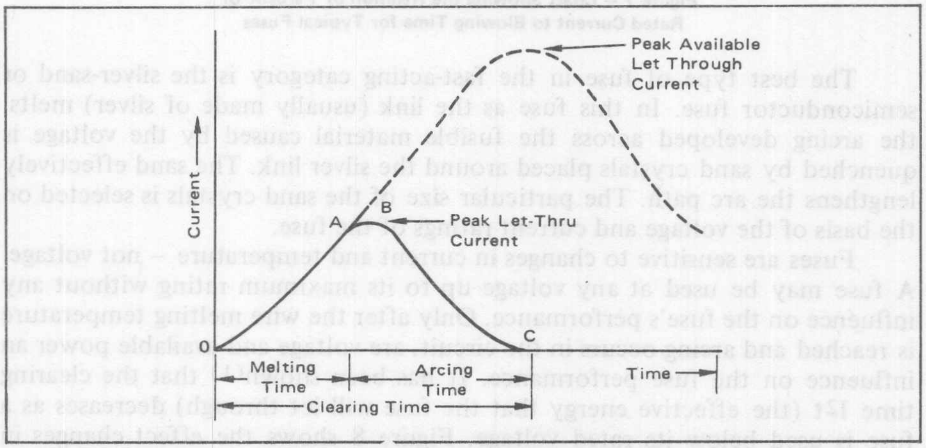


Figure 6 – Action of a Fuse in a Circuit Subjected to a Current Surge

Three basic types of fuses are available: normal-or medium-acting, fast-acting, and slow-acting (often referred to as "Slo-Blo"). The difference between the fast-acting and the normal-acting is a slightly different material is used for the link (this is the part of the fuse that melts) that results in the fast-acting fuse having a smaller thermal inertia. Similarly, the "Slo-Blo" fuse has a larger thermal inertia than the normal-acting fuse which results from use of a low temperature melting point alloy and a heat sink. Figure 7 shows the general blowing time relationship for the three types at various overload conditions. Note the large blowing time required for the "Slo-Blo" compared to the other two. It is because of this difference that only medium- and preferably fast-acting fuses are used to protect rectifiers. The fast-acting fuses are sometimes called current-limiting fuses because of their fast blow times, although all fuses could be regarded as current limiters.

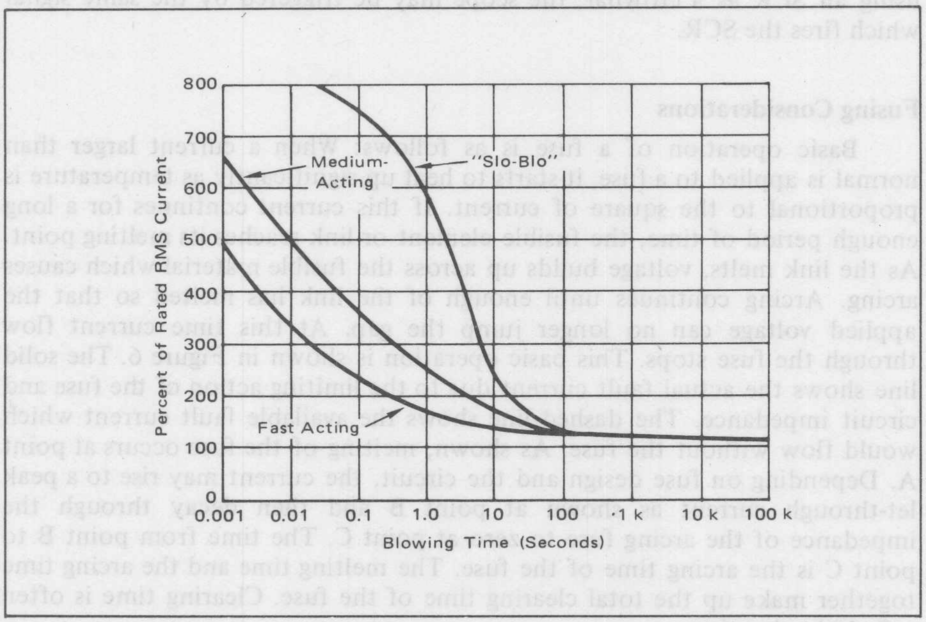


Figure 7 – Chart Showing the Relation of Percent of Rated Current to Blowing Time for Typical Fuses

The best type of fuse in the fast-acting category is the silver-sand or semiconductor fuse. In this fuse as the link (usually made of silver) melts, the arcing developed across the fusible material caused by the voltage is quenched by sand crystals placed around the silver link. The sand effectively lengthens the arc path. The particular size of the sand crystals is selected on the basis of the voltage and current ratings of the fuse.

Fuses are sensitive to changes in current and temperature – not voltage. A fuse may be used at any voltage up to its maximum rating without any influence on the fuse's performance. Only after the wire melting temperature is reached and arcing occurs in the circuit, are voltage and available power an influence on the fuse performance. It has been shown[1] that the clearing time I^2t (the effective energy that the fuse will let through) decreases as a fuse is used below its rated voltage. Figure 8 shows the effect changes in ambient temperature have on the ratings and blowing time.

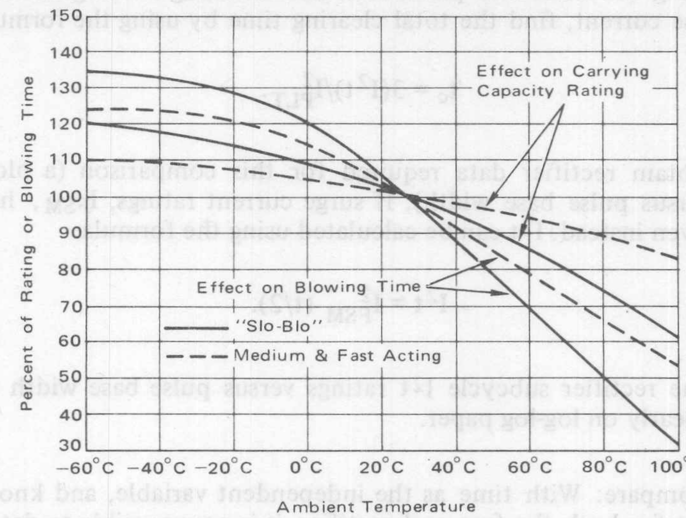


Figure 8 – Effect of Ambient Temperature on Operating Characteristics of Fuses.

There are two common ways to approach the problem of fuse protection. One way is to compare the fuse and rectifier on the basis of surge current, i.e., compare peak let-through current and rectifier surge current for a given fault current. Another way is to base the analysis on thermal energy, I^2t. It has been shown(2) that essentially equivalent heating occurs in a fuse and in a rectifier for a unit of I^2t where the I^2t of the fuse is based on a triangular waveform and the I^2t of the rectifier is based on a sinusoid waveform. Based on this second approach, the following steps can be used as a guide for fuse selection:

1. Select a fuse with a current rating stamped on it which is slightly higher than the current flowing through the rectifier under normal conditions.

2. Check the voltage rating on the fuse to insure that it is equal to or greater than the maximum circuit voltage.

3. Estimate or measure the available fault current. Since it is circuit dependent, it can be found analytically by dividing the source voltage by the system impedance with the fault placed in the system.

4. Enter the fuse tables with this information and find the worst-case peak let-through current, I_{PLT}, and the total clearing time I^2t for the selected fuse. A word of caution: fuse ratings are somewhat dependent upon mounting hardware. If a non-standard mounting is used, consult the fuse manufacturer to see if there is any change in the fuse ratings.

5. Using the latter two parameters and assuming a triangular model for fuse current, find the total clearing time by using the formula:[3,4]

$$t_c = 3(I^2 t)/I^2_{PLT}. \tag{1}$$

6. Obtain rectifier data required for this comparison (a plot of I^2t versus pulse base width). If surge current ratings, I_{FSM}, have been given instead, I^2t can be calculated using the formula:

$$I^2 t = I^2_{FSM}\ (t/2). \tag{2}$$

   The rectifier subcycle I^2t ratings versus pulse base width will plot linearly on log-log paper.

7. Compare: With time as the independent variable, and knowing the I^2t for both the fuse and rectifier, it is now possible to determine if the rectifier is actually protected.

8. Put the fuse in the circuit, short the load or simulate the fault and see if the rectifier is protected. Surge current should be examined on an oscilloscope.

Example:

Given 150 A fuse to protect an MR1205FL
Fault current = 3000 Amperes
$I^2t = 27{,}000\ A^2s$ from 1 to 8.3 ms.

For the 3000 A fault current, the total clearing I^2t and peak let-through current are found from Figures 9 and 10 to be 9500 A^2s and 2000 A. Using Equation 1 the clearing time is found as follows:

$$t_c = \frac{(3)\,(I^2 t)}{I^2_{PLT}} = \frac{(3)\,(9500)}{(2000)^2} = 7.1 \text{ ms.}$$

Thus the fuse will blow before the rectifier at a peak fault current of 2000 A. If the I^2t of the rectifier had not been given, it could have been found using the I_{FSM} rating.

I_{FSM} @ 1 cycle for the MR1205FL is 3600 A. Using Equation 2,

$$I^2 t = \frac{(3600)^2\ 8.3 \text{ ms}}{2} = 54 \times 10^3\ A^2 s.$$

This value is twice the value of 27×10^3 given on the data sheet, thus showing that I^2t decreases by a factor of 2 going from a pulse width of 8.3 ms to 1 ms, a not unusual situation.

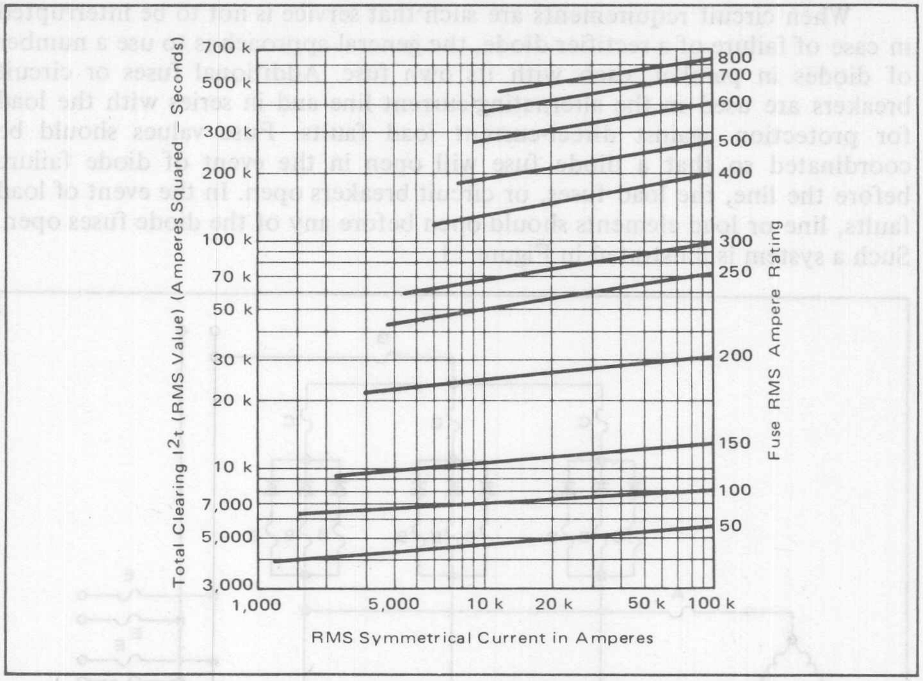


Figure 9 — Total Clearing Ampere Squared Seconds versus Available Fault Current, Type KAX Fuse

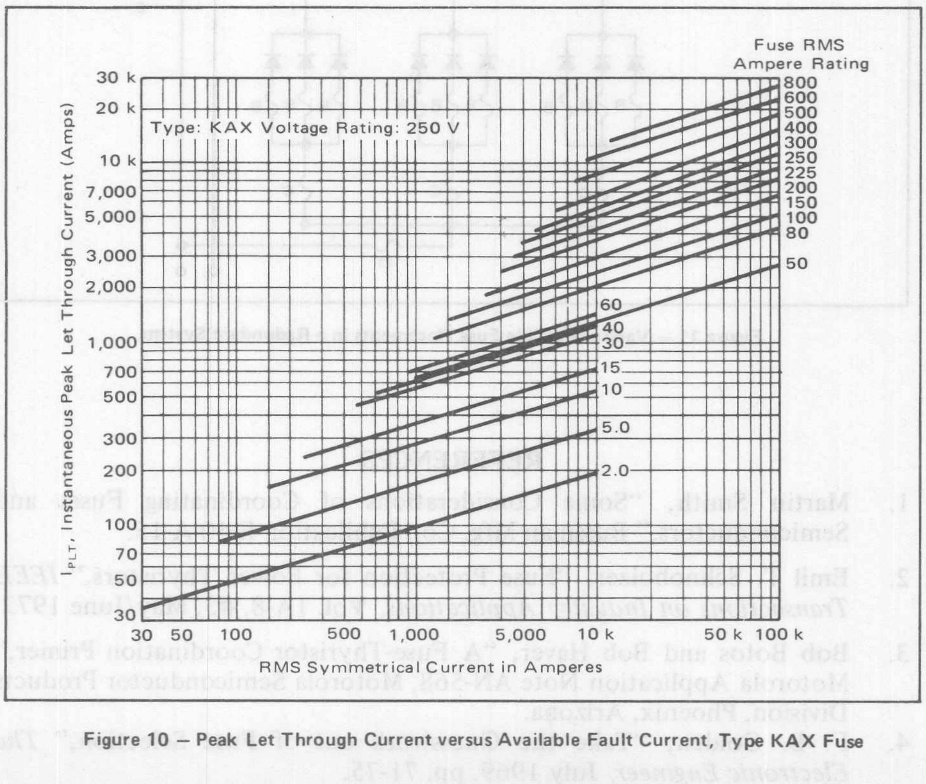


Figure 10 — Peak Let Through Current versus Available Fault Current, Type KAX Fuse

When circuit requirements are such that service is not to be interrupted in case of failure of a rectifier diode, the general approach is to use a number of diodes in parallel, each with its own fuse. Additional fuses or circuit breakers are used in the alternating-current line and in series with the load for protection against direct-current load faults. Fuse values should be coordinated so that a diode fuse will open in the event of diode failure before the line, the load fuses, or circuit breakers open. In the event of load faults, line or load elements should open before any of the diode fuses open. Such a system is illustrated in Figure 11.

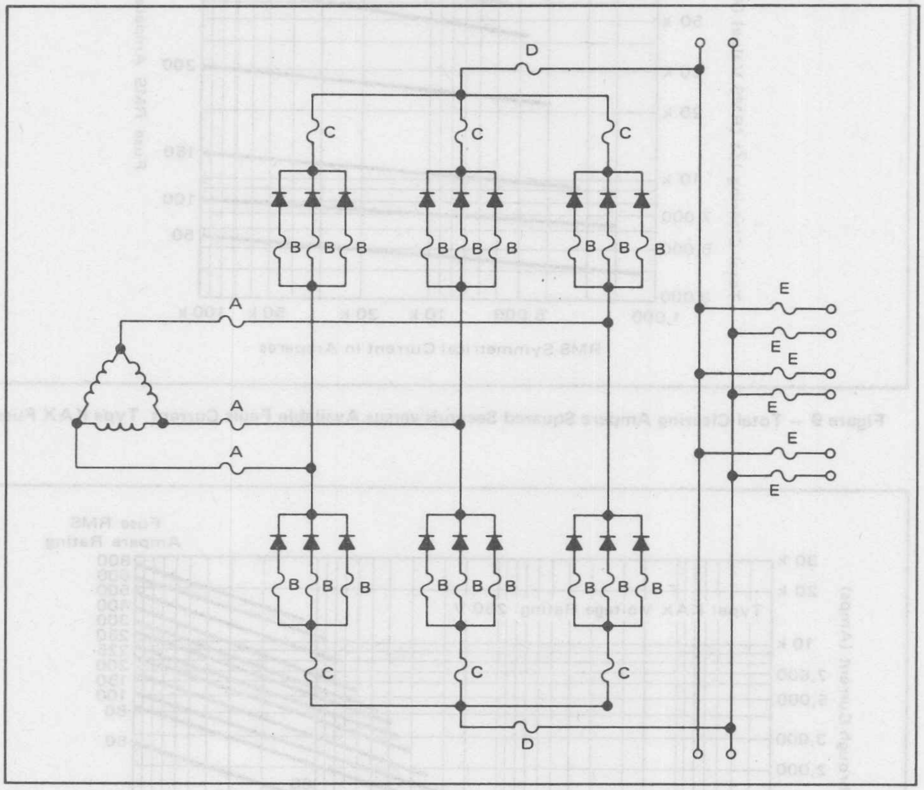


Figure 11 – Various Possible Fuse Placements in a Redundant System

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1. Martin Smith, "Some Considerations of Coordinating Fuses and Semiconductors," Bussman Mfg. Co., Publication E-60-A-15.
2. Emil T. Schnoholzer, "Fuse Protection for Power Thyristors," *IEEE Transactions on Industry Applications,* Vol. 1A-8, #3, May/June 1972.
3. Bob Botos and Bob Haver, "A Fuse-Thyristor Coordination Primer," Motorola Application Note AN-568, Motorola Semiconductor Products Division, Phoenix, Arizona.
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CHAPTER 10: THERMAL CONSIDERATIONS AND COOLING TECHNIQUES

Current ratings of rectifiers are inseparably linked to their thermal environment. Except for lead-mounted parts used at low currents, a heat exchanger is required in order to prevent the junction temperature from exceeding its rated limit, thereby running the risk of a high failure rate. Field failures of rectifiers are most often traceable to faulty thermal design. Failure rate of silicon rectifiers decreases approximately an order of magnitude for every 40°C decrease in junction temperature.

It is the purpose of this chapter to provide sufficient background information such that the designer can obtain a satisfactory and appropriate thermal design in equipment. Design charts and discussions of basic principles are presented.

Basically, there are three methods by which heat is transfered: (1) conduction (heat travels through a material), (2) convection (heat is transferred by physical motion of a fluid), and (3) radiation (heat is transferred by electromagnetic wave propagation). Semiconductors depend on conduction as a means of transferring heat from the junction to the external surface of the package and from the package to the heat exchanger, commonly called a heat sink. The package is cooled by convection and radiation. Both components are comparable in a still air ambient at sea level. Convection dominates when forced air or liquid cooling is used; radiation dominates in applications where semiconductors are used in a vacuum or at high altitudes.

THERMAL RESISTANCE CONCEPTS

The basic equation for heat transfer is generally written as

$$q = hA\Delta t \qquad (1)$$

where: q = rate of heat transfer or power dissipation (P_D),

h = heat transfer coefficient or thermal transmittance per unit area,

A = area involved in heat transfer,

Δt = temperature difference between regions of heat transfer.

Electrical engineers find it is easier to work in terms of thermal resistance defined as the ratio of temperature to power. From Equation 1 thermal resistance, $R\theta$ is:

$$R_\theta = \frac{\Delta t}{q} = \frac{1}{hA} \qquad (2)$$

The coefficient h depends upon the heat transfer mechanism used and various factors involved in that particular mechanism. The coefficient h may be thought of as thermal conductivity, regardless of the heat transfer mechanism. When designing cooling fins, it is simpler to use h rather than R_θ because cooling due to convection and radiation may be handled as two thermal paths in parallel.

An analogy between Equation 2, and Ohm's Law is often made to form models of heat flow. Note that Δt could be thought of as a voltage, thermal resistance corresponds to electrical resistance (R), and power (q) is analogous to current (I). This gives rise to a basic thermal resistance model for a semiconductor as indicated by Figure 1.*

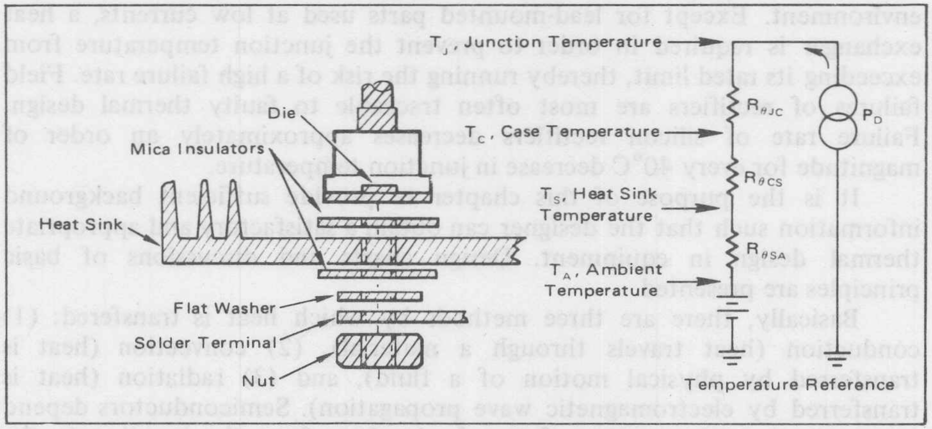


Figure 1 – Basic Thermal Resistance Model Showing Thermal to Electrical Analogy For a Semiconductor

The equivalent electrical circuit may be analyzed by Kirchoff's Law and the following equation results:

$$T_J = P_D\,(R_{\theta JC} + R_{\theta CS} + R_{\theta SA}) + T_A \qquad (3)$$

where: $R_{\theta JA}$ = total thermal resistance junction to ambient ($R_{\theta JC} + R_{\theta CS} + R_{\theta SA}$)

$R_{\theta JC}$ = semiconductor thermal resistance (junction to case),

$R_{\theta CS}$ = interface thermal resistance (case to heat sink),

$R_{\theta SA}$ = heat sink thermal resistance (heat sink to ambient).

The thermal characteristics of the semiconductor are described in Chapter 2 and will not be further discussed here. The interface thermal resistance resulting from imperfect mating surfaces and use of insulators may be appreciable in high current applications. Factors involved in minimizing $R_{\theta CS}$ are discussed in the next section. The remainder of this chapter is devoted to $R_{\theta SA}$. It is assumed that the design problem has been reduced to one where the total power dissipation of the rectifier and the required case temperature limit is known. Knowing the upper ambient temperature permits Equation 3 to be solved for the limit of $R_{\theta CS} + R_{\theta SA}$ which is the case to ambient thermal resistance, $R_{\theta CA}$. With rectifiers having significant reverse power losses, junction-to-ambient thermal resistance must be considered early in the design phase as shown in Chapter 2; however, the problem of providing a suitable case to ambient thermal resistance still exists.

*For lead-mounted rectifiers, most of the heat leaves the junction via the leads. The situation is analogous to that of the case-mounted counterpart, except the reference point is the lead instead of the case and the thermal resistance of the package from case-to-ambient may be significant. Lead-mounted parts are discussed in Chapter 2.

INTERFACE THERMAL RESISTANCE

When using stud-mounted, base-mounted, or press-fit rectifiers, attention must be given to the interface thermal resistance ($R_{\theta CS}$) between the rectifier and its heat sink. Proper mounting procedures must be followed to reduce $R_{\theta CS}$ to its lowest practical levels. The procedures include preparing the mating surfaces, applying thermal compound, and adhering to proper fastening techniques.

Table 1 shows appropriate values to use in various situations. It assumes that the parts are mounted properly in accordance with the instructions which follow and that the heat sink used has a reasonably flat, non-coated surface.

Package Type & Data					Interface Thermal Resistance (°C/W)						
Motorola Case #	JEDEC Outline #	Description	Average Heat Input Radius (in.)	Recommended Hole and Drill Size	Torque In-Lb	Metal-To-Metal Dry	Metal-To-Metal Lubed	With Insulator Dry	With Insulator Lubed	With Insulator Type	Motorola Kit #
56	DO-4	10-32 Stud 7/16" Hex	0.17	0.188", #12	15	0.41	0.41	1.24	1.06	3 mil Mica*	MH745
58	DO-5	1/4-28 Stud 11/16" Hex	0.22	0.25", #1	30	0.38	0.20	0.89	0.70	5 mil Mica*	MH746
43	DO-21	Press-fit	0.5	See Text		0.15	0.1	–	–	–	
1, 3, 4	TO-3	Diamond	0.5	0.25". #1		0.2	0.1	1.45	0.8	3 mil Teflon*	MK10
								0.8	0.4	2 mil Mica*	MK15
								0.4	0.35	Annodized Aluminum	MK20

*Insulator exhibit a long term creep which relieves the clamping pressure. As a result, thermal resistance values shown may increase by a factor of two to four times.

Table 1 — Typical Values for Interface Thermal Resistance and Other Package Data

Preparation of Mounting Surface

In general, surface flatness of machines or milled parts is satisfactory if they appear flat against a straight edge and are free from deep scratches. Castings or extrusions generally require spot-facing to insure flatness and finish. It is also necessary that the surface be free from all foreign material, film, and oxide (freshly bared aluminium forms an oxide layer in a few seconds). Unless used immediately after machining, it is a good practice to polish the mounting area with No. 000 steel wool, followed by an acetone or alcohol rinse. Thermal grease should be immediately applied.

Many aluminum heat sinks are black anodized for appearance, durability, performance and economy; however, anodizing is an electrical and thermal insulator which offers resistance to heat flow and, therefore, should be removed from the mounting area. Another treated aluminum finish is irridite, or chromate acid dip, which offers low resistances because of its thin surface. But, for optimum performance, it must be cleaned of oils and films that collect in the manufacture and storage of the sinks. For economy, paint is sometimes used for sinks; removal of the paint where the semiconductor is attached is mandatory because of the paint's high thermal resistance.

Anodize and some epoxy paints can be used for surface finish when it is necessary to electrically isolate the semiconductor case from the heat sink. This technique generally yields more consistant results than the use of insulators.

Thermal Compounds

To optimize contacts, thermal joint compounds are used to fill air voids between mating surfaces. Values of thermal resistivity vary from 0.10°C inches per watt for copper film to 1200°C inches per watt for air, whereas a satisfactory joint compound will have a resistivity of approximately 60°C inches per watt. Therefore, the voids, scratches, and imperfections which are filled with a joint compound, will have a thermal resistance of about 1/20th of the original value.

Joint compounds are a formulation of fine zinc particles in a silicone oil which maintains a grease-like consistency with time and temperature. The compounds should be applied in a very thin layer, applying a coating with a spatula or lintless brush, and wiping lightly to remove excess material. Alternately, a predetermined minimal amount may be placed around the center of the contact area; then in mounting, rotation and pressure will force the compound over the contact area. Some cyclic rotation of the package will help the compound spread evenly over the entire contact area. Experience will indicate whether the quantity is sufficient, as excess will appear around the edges of the contact area. Excess compound may be wiped away using a cloth wetted with acetone or alcohol.

Recommended Joint Compounds are:

1. Astrodyne – Conductive Compound-829
2. Dow-Corning – Silicone Heat Sink Compound-340
3. Emerson & Cuming, Inc. – Eccotherm, TC-4
4. George Risk Industries – Thermal Transfer Compound-XL500
5. General Electric – Insulgrease – G640, G641
6. IERC – Thermate
7. Thermalloy – Thermacote
8. Wakefield – Thermal Compound Type 120

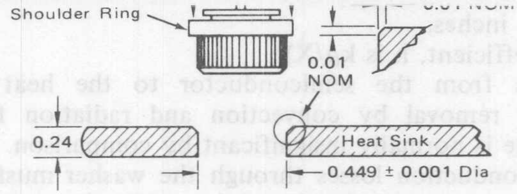
Fastening Techniques

When attaching stud-mount rectifiers, the hole for the stud should be only slightly larger than the stud and be without chamfer, i.e., the sides should be straight from top to bottom. No burrs should exist and the hole should not be threaded; a nut should be used to fasten the assembly.

Wherever possible, there should be no insulation between the diode and the heat sink. All mating surfaces should be coated with thermo-conductive grease because it fills the small areas of no contact. All grease should be kept away from the threaded portion of the diode because lubricated threads cause inconsistency in torquing requirements. The device should be tightened with a torque wrench close to its maximum torque rating. Care must be taken because low torque will cause the $R_{\theta CS}$ to increase greatly while excessive torque will destroy the device.

Press-fit rectifiers should be mounted according to the procedures outlined in the inset on the next page.

The use of aluminum heat sinks adds an additional problem: galvanic action may occur between rectifier and sink, if the assembly is placed in a corrosive atmosphere. To counteract this undesired action, Motorola rectifiers are normally nickel- or tin-plated. Consequently, precautions must be taken not to mar the finish.



The hole edge must be chamfered as shown to prevent shearing off the knurled edge of the rectifier during press-in. The pressing force should be applied evenly on the shoulder ring to avoid tilting or canting of the rectifier case in the hole during the press-in operation. Also, the use of a thermal joint compound will be of considerable aid. The pressing force will vary from 250 to 1000 pounds, depending upon the heat sink material. Recommended hardnesses are: copper — less than 50 on the Rockwell F scale; aluminum — less than 65 on the Brinell scale. A heat sink as thin as 1/8" may be used, but the interface thermal resistance will increase in proportion to the reduction of contact area. A thin chassis requires the addition of a back-up plate.

Mounting Details for Press-Fit Rectifiers

HEAT TRANSFER PRINCIPLES

The thermal resistance of the heat exchanger, or "heat sink" as it is commonly called, is an important part of the thermal design for stud or base-mounted rectifiers. Heat sinks may transfer heat to the ambient by natural convection and radiation, or forced air or liquid cooling may be employed. Conduction losses in the heat sink are also a factor in its performance. As a rough approximation for silicon junction rectifiers, handling power levels over 100 watts is more economical in terms of space and cost if forced air is used; levels over 2000 watts generally require liquid cooling. Schottky rectifiers, because of their lower maximum junction temperature limit, will require forced air or liquid cooling at lower power levels than those indicated. In terms of thermal resistance, values as low as 1°C/W can be achieved with large volume free convection heat sinks. Use of air flow can produce values as low as 0.05°C/W, while use of liquid cooling can closely approximate the "infinite heat sink".

In this section factors of importance in natural convection cooling, forced air cooling, and liquid cooling will be discussed. The intent is to acquaint the electrical engineer with the principles involved, not to provide a course on heat transfer. Reference 2 is an excellent point to begin further study; it has an extensive list of references.

Conduction

Conduction is a process of heat transfer in which heat energy is passed from one atom to the next, while the actual atoms involved in the transfer remain in their original positions. The thermal resistance which may be attributed to conduction, $R_{\theta(cond)}$, is determined by the following equation:

$$R_{\theta(cond)} = X/k\theta A \qquad (4)$$

where: $R_{\theta(cond)}$ = thermal resistance in °C/watt,

X = length of thermal path in inches,

$k\theta$ = thermal conductivity in W/° –in²,

A = the area perpendicular to the thermal path in square inches.

(heat transfer coefficient, h is $k\theta/X$).

Heat moves from the semiconductor to the heat exchanger by conduction; heat removal by convection and radiation from the semiconductor package is normally insignificant by comparison. If an insulating washer is used, conduction losses through the washer must be considered. The value of $R_{\theta(cond)}$ may be found by using the data of Table 2 in Equation 4. Conduction also plays a role in the operation of the heat sink, because the heat sink material offers resistance resulting in a temperature drop from the semiconductor contact area to the edge of the plate or fins. Clever heat sink design minimizes conduction losses. In large area plates, unless thick material is used, conduction losses are significant and play a key part in determining a design in which the volume of the heat sink material is minimized.

Materials	Conductivity W/°C-in²
Silver	10.70
Copper	9.75
Gold	7.86
Beryllia, 99.5% pure	6.20
Aluminum, pure	5.75
Aluminum, 68S	5.34
Beryllia, 95%	4.13
Magnesium.	4.16
Alumin 6061-T6	4.13
Red brass	2.92
Yellow brass	2.51
Beryllium copper	2.19
Pure iron.	1.99
Phosphor bronze	1.36
Soft steel	1.23
Monel	0.94
Lead	0.87
Hard Steel .	0.58
Thermal Compounds .	0.018
Mica.	0.015
Mylar Film.	0.0042
Air	0.00083

Table 2 – Thermal Conductivity of Various Materials at 27°C

Natural Convection

Convection is a term applied to the transfer of heat by the physical motion of a fluid, such as air or water. In natural convection, the air moves because of differences in density caused by temperature differences in the air below and above the fins. The following equation applies for the natural convection of vertical plates suspended in free air at ground level:(1)(2)

$$h_c = 2.21 \times 10^{-3} \left(\frac{T_S - T_A}{L} \right)^{1/4} \qquad (5)$$

where: h_c = the convection heat transfer coefficient in watts/in² –°C,

L = the height of the heat sink in inches,

T_S = the surface temperature of the heat sink in °C,

T_A = the ambient temperature in °C.

Figure 2 is a plot of Equation 5. Note that h_c is directly related to the difference in temperature between the plate and the ambient, with the result that the thermal resistance of a heat sink improves as the power applied increases. The constant is a function of air density, temperature of ambient air in contact with the plate, and orientation and shape of the heat sink. The value of 2.21 x 10^{-3} applies for standard pressure and temperature at sea level for rectangular plates suspended freely in still air. For other conditions the "constant" must be altered.

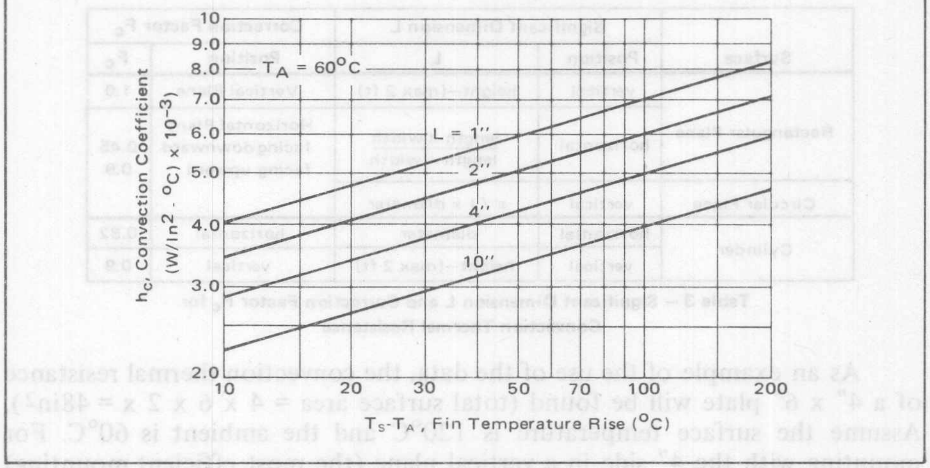


Figure 2 – Free Convection Coefficient for Rectangular Plates of Various Heights, L

Air density is a significant factor in convection cooling. Since density varies with altitude, a correction factor is indicated on Figure 3. Note that a 10% loss in effectiveness occurs at about 5000 feet. In space, convection is zero. Values for h_c must be multiplied by the number obtained from Figure 3 to obtain the proper value.

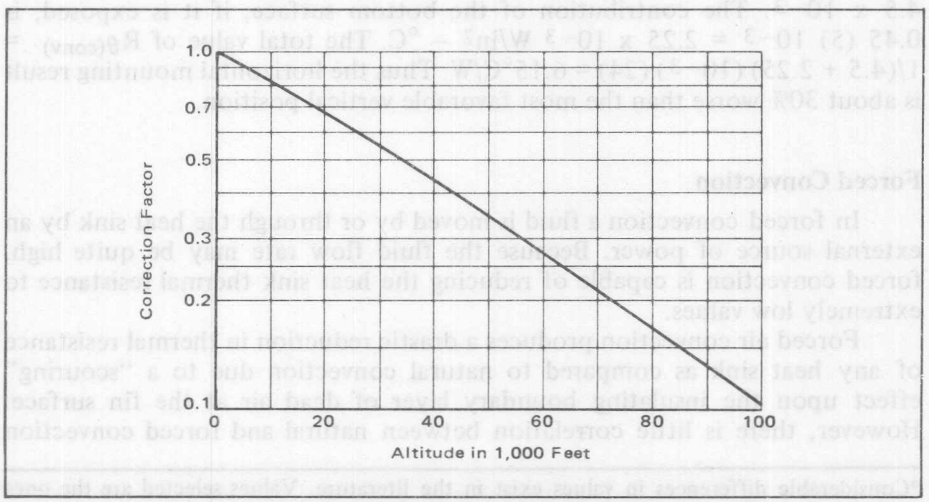


Figure 3 – Altitude Correction Factor for Free Convection Heat Transfer

correction factor F_c for rectangular, circular, and cylindrical surfaces in either a horizontal or vertical position. For horizontal mounting, the sum of the convection thermal transmittance from the top and bottom surfaces must be found. When both surfaces are exposed to air, the overall thermal resistance is about 25% higher than would be the case of a vertical plate of the same significant dimension L. For an enclosed chassis, the contribution of the bottom surface of the upper plate is neglegible.

Surface	Significant Dimension L		Correction Factor F_c	
	Position	L	Position	F_c
Rectangular Plane	vertical	height–(max 2 ft)	Vertical Plane	1.0
	horizontal	$\frac{\text{length x width}}{\text{length + width}}$	Horizontal Plane facing downward facing upward	 0.45 0.9
Circular Plane	vertical	π / I x diameter		
Cylinder	horizontal	diameter	horizontal	0.82
	vertical	height–(max 2 ft)	vertical	0.9

Table 3 – Significant Dimension L and Correction Factor F_c for Convection Thermal Resistance

As an example of the use of the data, the convection thermal resistance of a 4″ x 6″ plate will be found (total surface area = 4 x 6 x 2 x = 48in^2). Assume the surface temperature is 120°C and the ambient is 60°C. For mounting with the 4″ side in a vertical plane (the most efficient mounting) read h_c = 4.4 x 10^{-3} W/in^2 – °C from Figure 2. Using Equation 4, $R_{\theta(conv)}$ = 1/(4.4)(10^{-3})(48) = 4.74°C/W. If the plate were mounted with the 6″ side in a vertical plane, h_c = 4 x 10^{-3} W/in^2 – °C resulting in a 10% increase in $R_{\theta(conv)}$.

For horizontal mounting, a new value of L must be found from the relations in Table 3. Dimension L calculates to be 2.4″ resulting in h_c = 5 x 10^{-3} W/in^2 – °C at $T_S - T_A$ = 60°. The area of each side is 24 in^2. Using the correction factors given in Table 3, $h_{c\ (top)}$ = (0.9) (5) 10^{-3} = 4.5 x 10^{-3}. The contribution of the bottom surface, if it is exposed, is 0.45 (5) 10^{-3} = 2.25 x 10^{-3} W/in^2 – °C. The total value of $R_{\theta(conv)}$ = 1/(4.5 + 2.25) (10^{-3}) (24) = 6.15°C/W. Thus the horizontal mounting result is about 30% worse than the most favorable vertical position.

Forced Convection

In forced convection a fluid is moved by or through the heat sink by an external source of power. Because the fluid flow rate may be quite high, forced convection is capable of reducing the heat sink thermal resistance to extremely low values.

Forced air convection produces a drastic reduction in thermal resistance of any heat sink as compared to natural convection due to a "scouring" effect upon the insulating boundary layer of dead air at the fin surface. However, there is little correlation between natural and forced convection

*Considerable differences in values exist in the literature. Values selected are the ones which seem to be generally borne out in practice.

performance. Natural convection cooling is primarily dependent upon the volume and material of the heat sink while forced convection cooling can be related to the air flow, fin spacing, and the degree of coupling to the air stream.

The heat transfer coefficient for the case of turbulent air flow parallel to a plate may be expressed as

$$h_f = 6.63 \times 10^{-3} \quad (V^3/L)^{1/4} \qquad (6)$$

where: h_f = the forced convection heat transfer coefficient in watts/in^2 − °C,

V = the free stream velocity in linear feet per minute,

L = length of the plate in inches.

The constant is affected by air density and temperature. The value given is based upon operation at sea level at an average air temperature over the heat exchanger of 60°C. As a design aid, values have been calculated from Equation 6 and are plotted in Figure 4. Note that a short dimension in the flow direction increases the coefficient significantly. The curves stop at points where the flow is becoming laminar and, consequently, Equation 6 does not apply. In the laminar region, h_f is higher than an extrapolation of the curves would indicate. Equation 6 should not be used for plates with L less than 4″, as the flow is laminar when it first encounters the plate. Short plates do not permit development of turbulent flow.

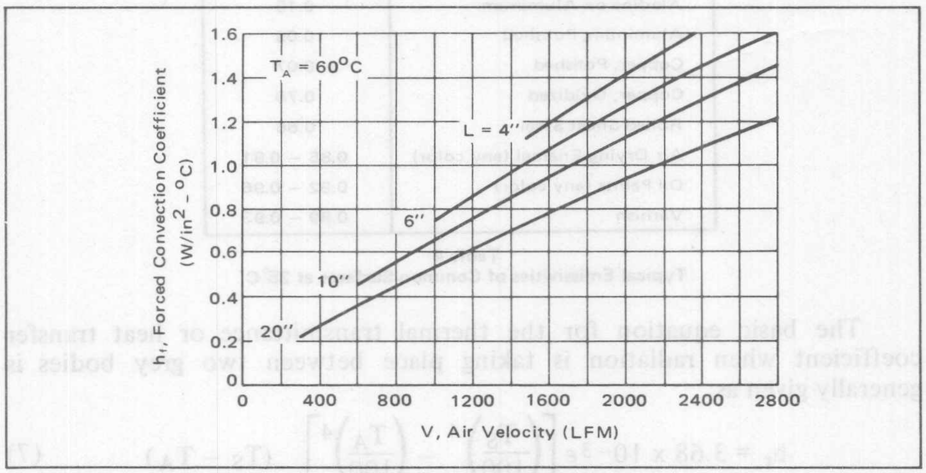


Figure 4 – Heat Transfer Coefficient for Forced Air Convection

As an example, the forced convection thermal resistance will be found for the 4″ x 6″ plate (surface area = 48″^{2}) used in the previous example. Assume that the 4″ side is parallel to the flow direction and the air flow rate is 2000 LFM. Reading from Figure 4, $h_f \approx 1.4$ W/in^2 −°C. $\therefore R\theta = 1/(1.4)(48) = 0.015$°C/W. This value is about 300 times better than that obtained with natural convection; however, improvements this large are not achieved in practice because of material thermal resistance losses.

Water or liquid cooling is similar in principle to that of forced air. The heat transfer coefficient is related to velocity in a manner similar to that described by Equation 6. Normally, the liquid cooled system is purchased as a unit and its characteristics are provided by the manufacturer.

Radiation

The third process by which heat may be transferred is radiation. The ability of a body to radiate thermal energy at any particular wavelength is determined by the body temperature and surface characteristics. An ideal radiator is called a blackbody, which by definition radiates the maximum amount of energy at any wavelength. The ratio of energy emitted by any surface to that of a blackbody at the same temperature is called the emissivity ϵ.

Incident radiation on a surface is partially absorbed, reflected, and in some cases, transmitted through the surface. However materials used for heat sinks are opaque and do not transmit radiation. The ability of a surface to absorb the total incident radiation on it is defined by the term absorptivity α. As with the emissivity, the absorptivity of a surface is dependent upon the source temperature (i.e. wavelength of incident radiation) and the receiving body surface characteristics.

Many materials exhibit the property of having $\alpha = \epsilon$ when the absorber and the emitter are at temperatures within 50°C of each other. These materials are called grey bodies and emissivity values for some common cases are listed in Table 4.

Surface	Emissivity
Aluminum, Anodized	0.7 – 0.9
Alodine on Aluminum	0.15
Aluminum, Polished	0.05
Copper, Polished	0.07
Copper, Oxidized	0.70
Rolled Sheet Steel	0.66
Air Drying Enamel (any color)	0.85 – 0.91
Oil Paints (any color)	0.92 – 0.96
Varnish	0.89 – 0.93

Table 4
Typical Emissivities of Common Surfaces at 25°C

The basic equation for the thermal transmittance or heat transfer coefficient when radiation is taking place between two grey bodies is generally given as:

$$h_r = 3.68 \times 10^{-3} \epsilon \left[\left(\frac{T_S}{100} \right)^4 - \left(\frac{T_A}{100} \right)^4 \right] \Big/ (T_S - T_A) \qquad (7)$$

where: h_r = radiation heat transfer coefficient in W/in^2–°C,

ϵ = emissivity,

T_S = surface temperature in °K,

T_A = ambient temperature in °K.

As with convection, the thermal resistance is inversely proportional to area. Since temperature affects the results in a complex manner, Equation 7 is plotted on Figure 5, in terms of °C. Observe the strong effect of temperature upon thermal resistance. As with convection, a similar problem with temperature drop occurs in large area plates due to resistance losses, whereby the extremities of the heat sink are not as effective as the center.

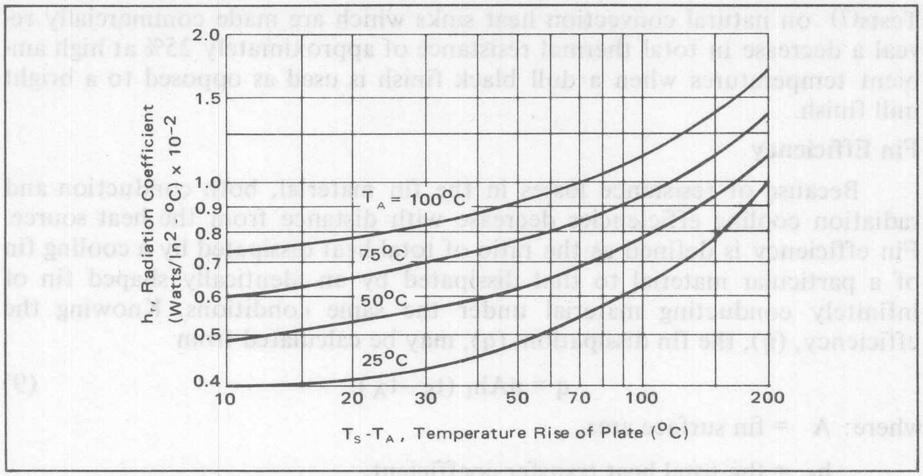


Figure 5 – Radiation Coefficient for a Black Body Having an Unobstructed Pattern

If radiation is obstructed by nearby objects, the "constant" in Equation 7 will need to be modified by a factor (F_r) smaller than unity. If the object is at the same temperature as the fin, an adjustment can be made by considering the geometry of the radiation pattern. It is generally satisfactory to consider an unobstructed fin's radiation as originating at the center of the fin and being spherical (hemispherical on each side of the fin). An obstruction will interrupt radiation, or subtract a sector from the sphere. F_r is approximately the ratio of the solid angle remaining in the obstructed sphere to the solid angle (4π steradians) of the complete sphere.

The fin should be shielded from bodies of higher temperature. Otherwise, the fin will be heated by radiation instead of being cooled.

Equation 7 also assumes that the radiating body is small compared to the enclosing body. Other configurations require a modification of the emissivity value. For the case of two large parallel plates or for the case where the enclosed body is large compared to the enclosing body, the effective emissivity ϵ_f is given by:

$$\epsilon_f = \frac{1}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}, \tag{8}$$

where ϵ_1 and ϵ_2 are the emissivities of the two surfaces. Other situations require an in-depth analysis of the problem.[3]

As an example of the use of the data for radiation thermal resistance, $R_{\theta(rad)}$ for the 4″ x 6″ plate previously used will be found. From Figure 5, at $T_A = 60°C$ and $T_S = 120°C$, $h_r = 0.7 \times 10^{-2}$ W/in^2 – °C. If the plate were painted (preferably black), $\epsilon \approx 0.9$, and $R_{\theta(rad)} = 1/(0.9)(0.7)(10^{-2})(48) = 3.3°C/W$. This value is less than the convection value because of the high emissivity and high surface temperature allowed.

Surface emissivity is unimportant when forced air or liquid cooling is used, as the effect of radiation is negligible. However, for natural convection cooling, radiation plays a significant roll and surfaces having high emissivity should be used. As Table 4 shows, polished surfaces should be avoided and anodized aluminum and painted surfaces are preferable. The surface finish, however, should not be present at the interface of the semiconductor and the heat sink. (See previous section – "Interface Thermal Resistance").

Tests[7] on natural convection heat sinks which are made commercially reveal a decrease in total thermal resistance of approximately 25% at high ambient temperatures when a dull black finish is used as opposed to a bright mill finish.

Fin Efficiency

Because of resistance losses in the fin material, both conduction and radiation cooling efficiencies decrease with distance from the heat source. Fin efficiency is defined as the ratio of total heat dissipated by a cooling fin of a particular material to that dissipated by an identically shaped fin of infinitely conducting material under the same conditions. Knowing the efficiency, (η), the fin dissipation, (q), may be calculated from

$$q = \eta A h_t \,(t_S - t_A). \tag{9}$$

where: A = fin surface area,

h_t = the total heat transfer coefficient,

T_S = the temperature of the heat sink at the heat source,

T_A = the temperature of the ambient.

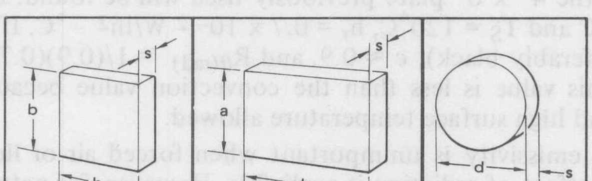
Similarly the fin thermal resistance $R_{\theta SA}$ is

$$R_{\theta SA} = \frac{1}{\eta A h_t} \tag{10}$$

If fins are made of relatively thick highly conductive material, fin efficiency is close to 100% and the total fin thermal conductance is the sum of the convection and radiation components. At the other extreme, if the fin is quite thin, the fin extremities are ineffective because of high resistance losses. Both extremes are wasteful of material and costly but the latter extreme is encountered when a chassis or other structure is used as a cooling fin for semiconductors. The range between these extremes is rather narrow.

Evidently, the only work directly pertinent to semiconductor cooling fins was performed by Werner Luft[1,4,5] a number of years ago. The information presented in this section is based upon this work.

To make the analysis more manageable, it was performed using a circular fin, and heat transfer by means of convection and radiation from the fin edge was neglected. The more commonly used geometries are handled by converting their dimension to an equivalent radius using the formulas in Table 5. The fin thickness (S) is generally a negligible factor in the equivalent radius.



$\sqrt{\dfrac{b^2 + 2bs}{\pi}}$	$\sqrt{\dfrac{a\,b + (a + b)\,s}{\pi}}$ (Satisfactory for $b \leqslant 2a$)	$\dfrac{d}{2}\sqrt{1 + \dfrac{2s}{d}}$

Table 5 – Equivalent Outer Radius (r_o) For Various Fin Geometries

A factor to consider in fin efficiency is the heat input radius, r_i. Figure 6 shows how it is found for the popular stud and diamond base packages. It is essentially the average value of the dimensions of the heat input source. Values are included in Table 1.

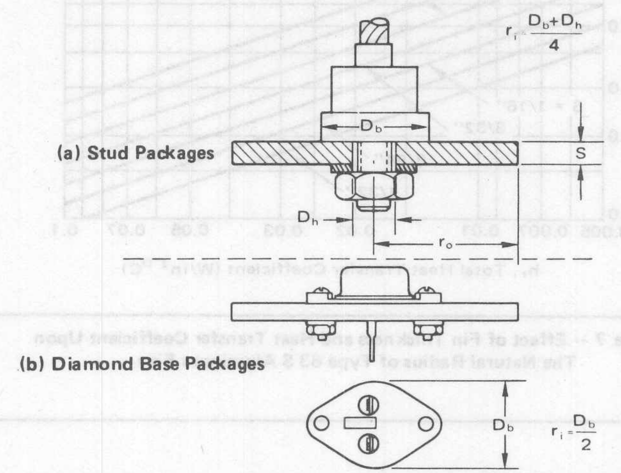


Figure 6 – Relation of Semiconductor Device Dimensions to Heat Input Radius r_i

By analyzing the temperature drop and heat dissipated by a volume element in an annular ring, a parameter is discovered which is a characteristic of the material and the heat transfer coefficient. This parameter, which plays an important role in fin efficiency, is called the "natural radius" of the fin (R) and is given by

$$R = \sqrt{k\theta S/2h_t} \tag{11}$$

where: $k\theta$ = the thermal conductivity of the fin material,

S = fin thickness,

h_t = total heat transfer coefficient of the fin.

For convenience in problem solving, Equation 11 is plotted in Figure 7 for 63S aluminum plates of standard thicknesses. Since the product $k\theta S$ is a constant for any one of the curves of Figure 7, the data may be used for heat sinks of other material by considering the thermal conductivity data of Table 2. For example, since copper has almost twice the conductivity of 63S aluminum, a copper plate of 1/32″ has the same relationship of h_t to S as does a 1/16″ aluminum plate.

Further analysis yields the equations necessary to plot Figure 8 and the fact that an optimum fin design is achieved when the fin efficiency is 50%. An optimum fin is taken as one which has minimum volume and therefore minimum material which generally results in minimum cost. For the optimum fin, the outer radius is approximately equal to the natural radius (when the fin outer radius is large compared to the heat input radius).

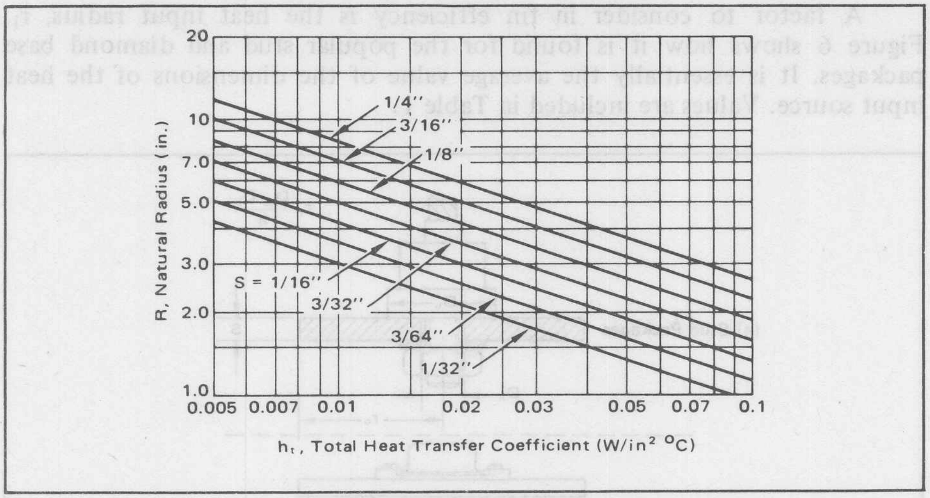


Figure 7 – Effect of Fin Thickness and Heat Transfer Coefficient Upon The Natural Radius of Type 63 S Aluminum Fins

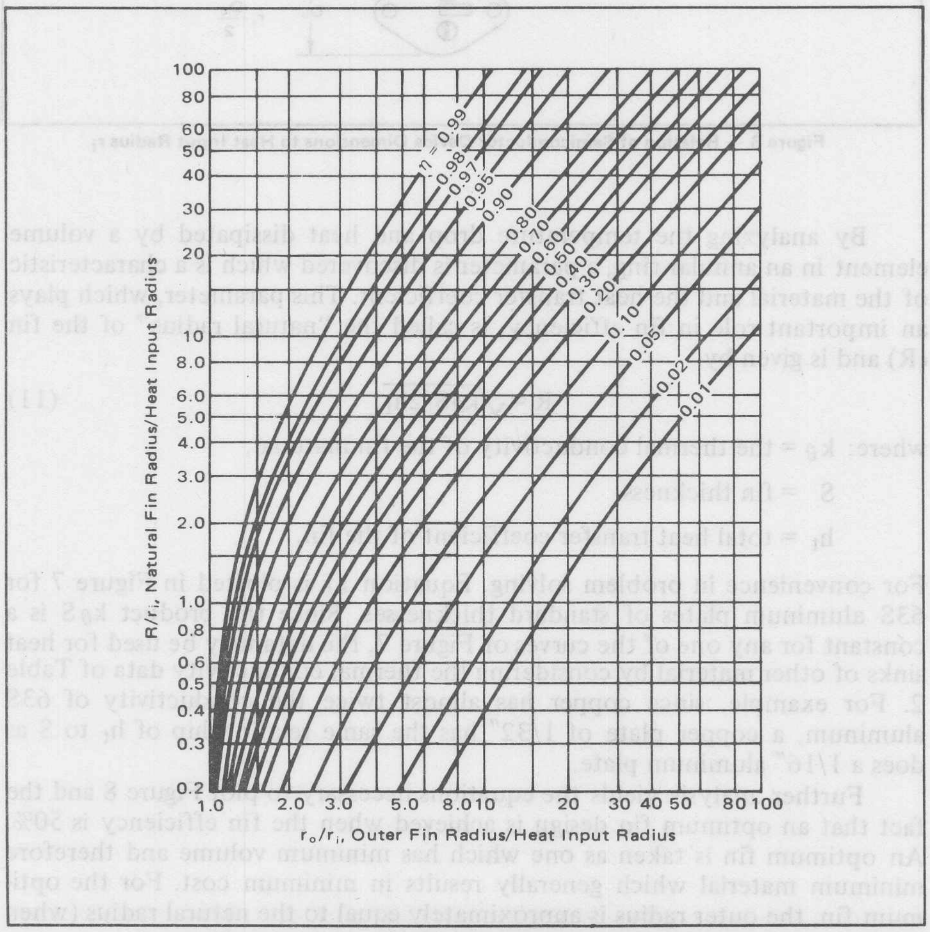


Figure 8 – Fin Efficiency η as a Function of R/r_i and r_o/r_i

To illustrate the use of the data, the efficiency of the 4″ x 6″ plate used in the previous examples will be discussed. Assume a DO-5 package is attached, which has an effective heat input radius close to 0.22 inches. The effective outer radius r_o from Table 5 is $\sqrt{24/\pi}$ (neglecting S) or 2.78″. ∴ $r_o/r_i = 12.6$. For an optimum fin ($\eta = 50\%$) $R/r_o \approx 12.6$ from Figure 8. ∴ R = 2.78″ The fin thickness is determined from Equation 11 or Figure 7. From the previous two examples, $h_t = (0.63 + 0.44)\ 10^{-2} = 0.0107$. Therefore, S may be less than 1/32″ for an aluminum fin. Overall thermal resistance is found from Equation 10 and is 3.9 °C/W for this example.

An improvement in fin efficiency or a reduction in size for a desired thermal resistance can be achieved by increasing the radius of the heat source. In practice, this can be achieved by brazing copper material to the heat sink. Suppose that 2 inch diameter discs are brazed to each side of the plate in the above example and that the thermal resistance of the discs is negligible. Now $r_o/r_i = 2.78$ and $R/r_i = 2.78$ also. From Figure 8, the fin efficiency is increased to 80%. The advantage of a large semiconductor package over a smaller one is thus also apparent.

APPLICATION AND CHARACTERISTICS OF HEAT SINKS

The material in this section provides general practical information necessary to efficiently select and use heat sinks in free and forced convection. In most cases, a commercial heat sink will be used. Its most important characteristics are specified by the manufacturer; by using the basic principles of heat transfer discussed in the previous section, the behavior of heat sinks under a variety of conditions may be predicted. Furthermore, the data for Figures 3 through 8 may be used to design single-fin heat sinks and to obtain the thermal resistance of a metal chassis.

Free Convection Cooling

Heat sinks are available in an endless assortment of sizes, shapes, colors, and materials; the manufacturer should be contacted for exact design data. It is convenient for discussion purposes to group heat sinks into three categories:

1. Flat vertical-finned types. Normally aluminum extrusions with or without an anodized black finish, they are unexcelled for natural convection cooling and provide reasonable thermal resistance at moderate air-flow rates for forced convection.
2. Cylindrical or radial vertical-finned types. Normally cast aluminum with an anodized black finish, they are used when maximum cooling in minimum lateral displacement is required.
3. Cylindrical horizontal-finned types. Normally fabricated from sheet-metal rings with a painted black matte finish, they are used in confined spaces for maximum cooling in minimum vertical displacement but are less efficient than the other two types.

Tests[6][7] conducted indicate, that in well designed heat sinks, the thermal resistance can be related fairly well to the surface area and the

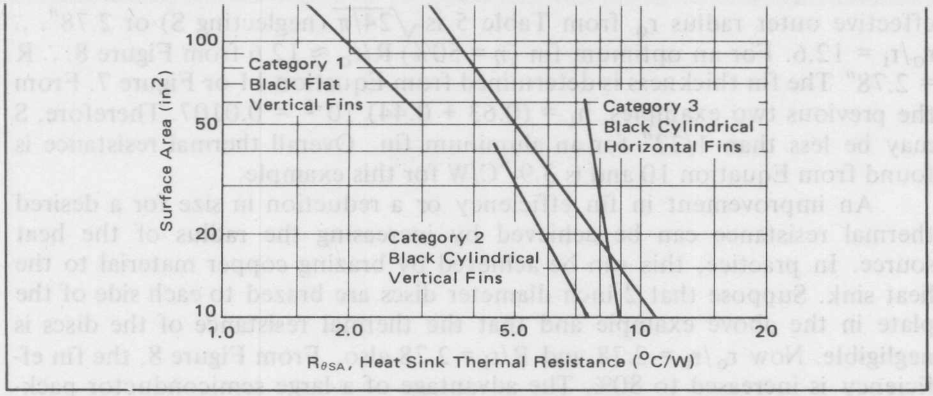


Figure 9 — Relation of Surface Area to Thermal Resistance for Numerous Commercial Aluminum Heat Sinks as Compared to an Aluminum Plate

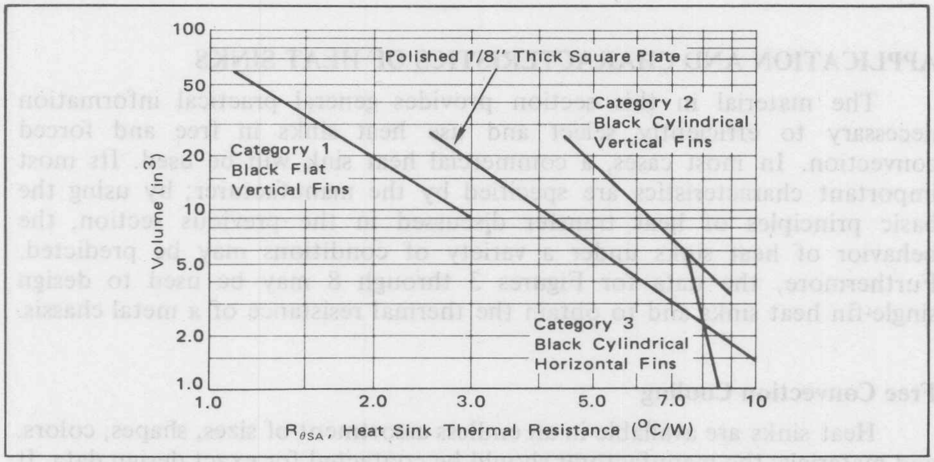


Figure 10 — Relation of Volume to Thermal Resistance for Numerous Aluminum Heat Sinks as Compared to an Aluminum Plate

volume of the heat sink is illustrated by Figures 9 and 10. The data of most interest is for heat sinks of categories 1 and 2; the category 3 types do not fit into a pattern and are of little interest for power rectifiers. A heat sink typical of those in category 1 is the Thermaloy 6500 series. Its steady state characteristics are shown in Figure 11. The slope of the curve varies from 3°C/W at low power levels to about 2°C/W at high levels. The improvement in thermal resistance is due to the convection and radiation components becoming more effective as temperature increases. The transient characteristics are shown in Figure 12. Note that the temperature below 2 minutes is proportional to the square root of time – a characteristic of one dimensional heat flow. The time to reach equilibrium is dependent upon the mass of the heat sink and requires about 20 minutes. Note that at times less than thermal equilibrium, the effective thermal resistance can be quite low. Therefore, patience is required when evaluating the overall thermal behavior of a system.

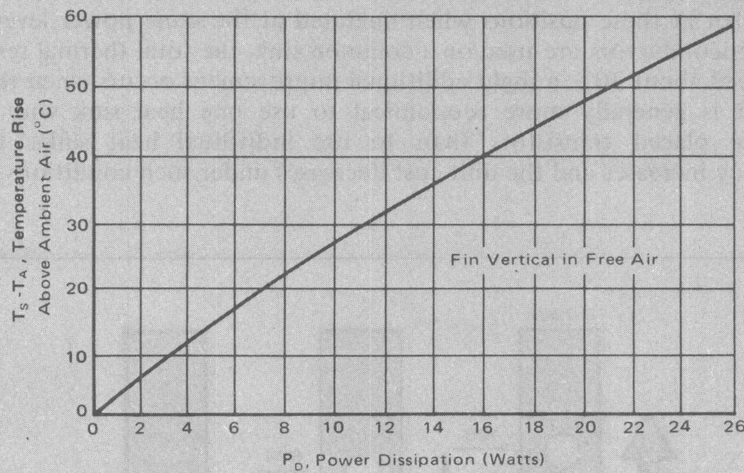


Figure 11 — Thermaloy 6500 series Heat Sink Thermal Characteristics

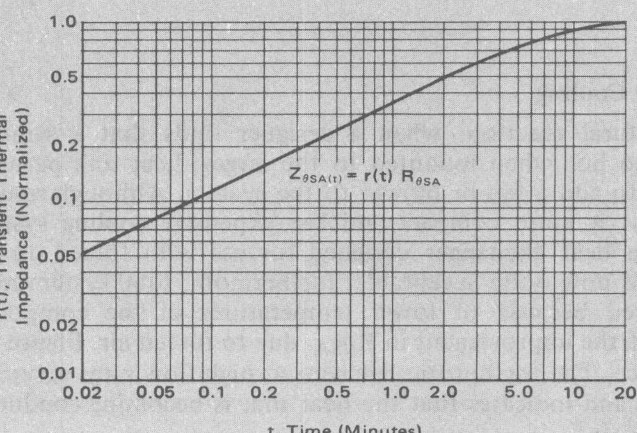


Figure 12 — Thermal Response of Thermaloy 6500 Heat Sink

The placement of the semiconductor on the heat sink is important in order to achieve lowest overall thermal resistance. Figure 13 shows the optimum positions. Tests(8) indicated case temperatures were within 1°C of each other at these positions when operated at the same power level. When two semiconductors are used on a common sink, the total thermal resistance is reduced about 30%; a slight additional improvement occurs when three are used. It is generally more economical to use one heat sink with several properly placed transistors than to use individual heat sinks. Cooling efficiency increases and the unit cost decreases under such conditions.

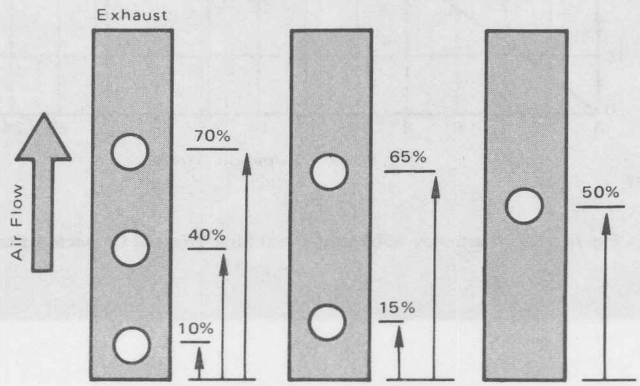


Figure 13 – Proper Rectfier Placement. Located in this fashion, each semiconductor will operate at the same case temperature and maximize the heat sink performance. In free convection, mounting must be vertical as shown (from October 1966 "ELECTRONIC PRODUCTS").

Forced Air Cooling

A natural reaction, when a designer finds that a semiconductor is running too hot when mounted to the largest heat sink permissible in the system, is to add a fan or blower to the system. Although results may seem satisfactory, a more compact and less expensive cooling system generally results if a heat exchanger designed for use with forced air is used. Fan reliability is now quite acceptable; furthermore, total system reliability may be enhanced because of lower temperatures of the components. As an example of the improvement in $R_{\theta SA}$ due to forced air, Figure 14 illustrates performance, The asymptotic behavior at high flow rates is typical of forced air cooling and indicates that the heat sink is becoming conduction limited.

When forced air cooling is employed, an interlock is generally necessary to prevent catastrophic system failure in the event of a blower malfunction. The use of an air-switch, comprised of a moving vane in the air flow mechanically coupled to a microswitch, can be used to interlock the electrical system.

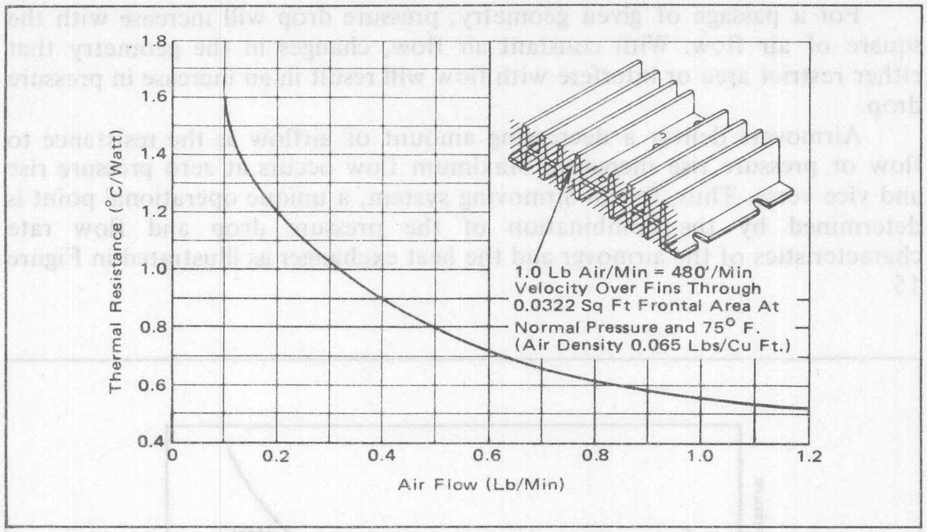


Figure 14 – Performance Under Forced Air Flow of Thermaloy 6500 Natural Convection Heat Sink.

Air Flow – The basic flow rate equation is

$$\Delta T = 1.76\ P_D/VA, \tag{12}$$

where ΔT = the change in air temperature in C,

P_D = the power dissipation in watts,

V = air velocity in linear feet per minute (LFM),

A = area of duct or chamber in square feet.

For example, if a flow rate of 500 LFM is required in a one square foot duct and the power to be dissipated is 1000 watts, the air temperature will increase by 3.5°C. The product VA is the volume of air flow required in cubic feet per minute (CFM).

Most efficient use of a given air flow will be achieved by locating components demanding minimum temperature rise (for example, semiconductors) closer to the inlet end of the cooling column and locating those elements for which maximum temperature rise is permitted (for example power resistors) at the exhaust end.

Determination of the required air flow must also take into account the location of the airmover (fan or blower). If the airmover is located at the intake, its own heat loss must be added to the power which the system is required to dissipate. In this location, however, the ambient temperature which the blower experiences will be relatively low. At the exhaust, the airmover operates in a higher ambient temperature but its own power loss does not raise the ambient air of the assembly and is, therefore, generally preferable.

Pressure Drop – An important aspect of forced air cooling is that of pressure drop. There is always a frictional resistance to fluid flow which is a function of geometry, velocity, and properties of the fluid. The resistance causes a back pressure, often called pressure drop, ΔP.

either restrict area or interfere with flow will result in an increase in pressure drop.

Airmovers deliver a decreasing amount of airflow as the resistance to flow or pressure rise increases. Maximum flow occurs at zero pressure rise and vice versa. Thus, for an airmoving system, a unique operational point is determined by the combination of the pressure drop and flow rate characteristics of the airmover and the heat exchanger as illustrated in Figure 15.

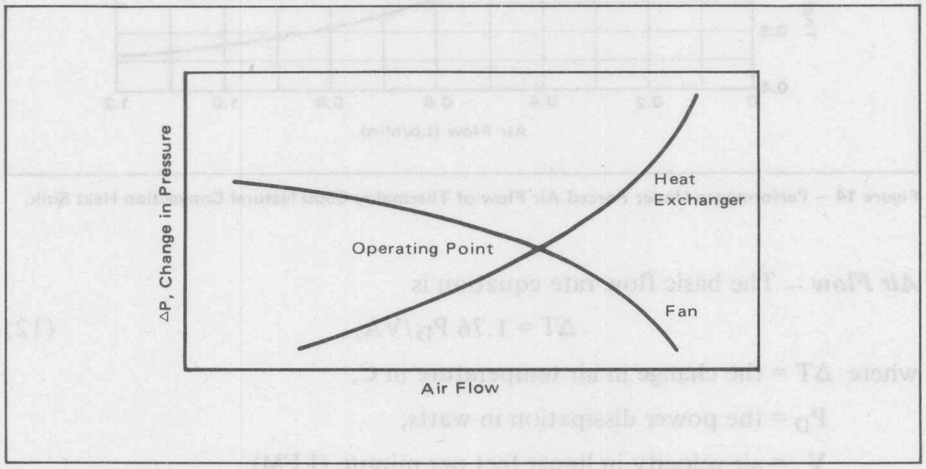


Figure 15 – System Operating Point. The Operational Point of a Cooling System of Given Geometry and a Given Fan Occurs at the Intersection of the System's Pressure Drop vs. Air Flow, and of the Fan's Pressure Rise vs. Air Flow.

Except for long straight ducts and certain bends and transition pieces, pressure drop is difficult or impossible to calculate. It is generally simpler to mount any type of airmover in the system and measure the resulting flow and pressure. Even if only one point is obtained, a system characteristic or impedance curve may be derived by assuming the impedance curve is quadratic. Knowing the CFM required, the resulting pressure is read from the impedance graph and an airmover meeting these requirements may be selected.

Note that an increase in flow from 50 to 100 CFM on the curve would increase the pressure requirements from 1.0 inch to 4.0 inches, which is a large increase. At a certain point, if more air is required, the designer is well advised to open air passages in the system so that the impedance is lowered, rather than increasing the pressure capabilities of the airmover.

For a given flow rate, and fixed volume, any change in geometry that increases the heat transfer will increase pressure drop causing the operational point on Figure 15 to move to the left. Therefore, for every system-and-fan combination, there is an optimum fin geometry. If volume is critical, it is best to select a cooler-fan combination from a manufacturer. Often, semiconductor manufacturers offer rectifier-heat sink assemblies designed for forced air service such as the MRA363 shown in Figure 16.

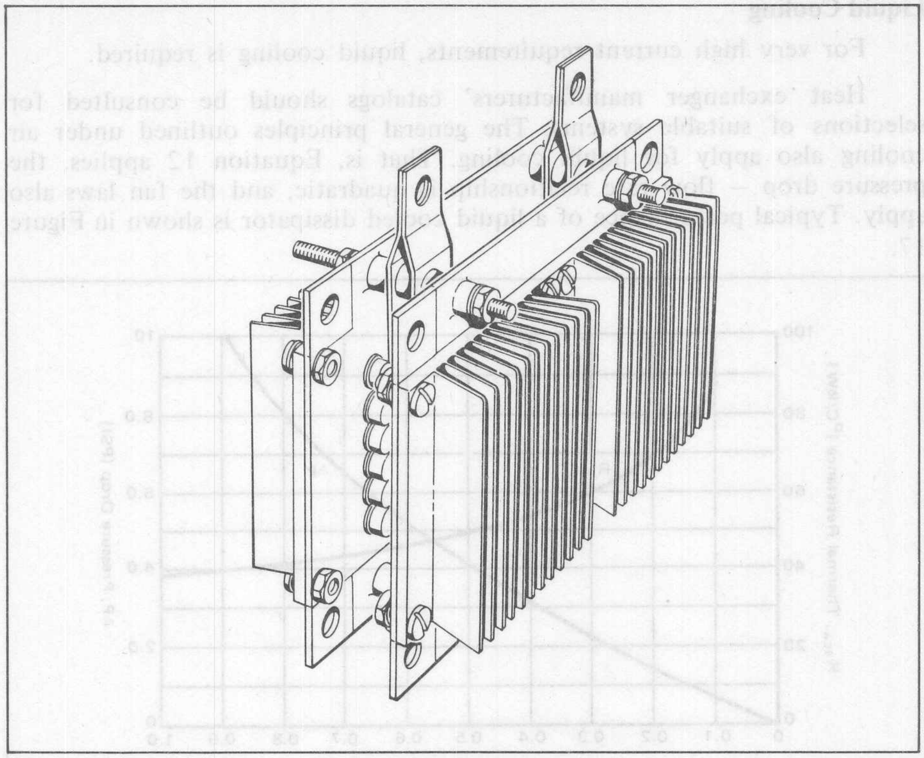


Figure 16 – A 650 Ampere Rectifier for 3-Phase Service Having Integral Heat Sink Designed for Forced Air Systems.

Fan Laws

1. Speed: The following fan laws express the manner in which the various quantities, in any fixed system, vary with speed of the air moving devices:

a) CFM varies directly with rpm,
b) SP (static pressure) varies as the square of the rpm,
c) HP (horsepower) varies as the cube of the rpm.

Note that if the impeller speed is doubled, the CFM is doubled, the static pressure is multiplied by 4 and the horsepower required is multiplied by 8.

2. Density: The performance rating of any impeller acting at a constant speed in a fixed system will be altered by a change in air density in the following manner:

a) CFM remains constant,
b) SP varies directly with air density.

Density is as important as velocity in forced convection cooling. Since density decreases with altitude, an airmover which has just sufficient capacity at sea level is inadequate at 50,000 feet. In order to provide an airmover which will function efficiently at all altitudes, special slip motors are available which operate at higher speeds as the load decreases. Consequently, the motor maintains a constant mass flow rate in terms of pounds per minute, in spite of the changes in density caused by altitude.

Liquid Cooling

For very high current requirements, liquid cooling is required.

Heat exchanger manufacturers' catalogs should be consulted for selections of suitable systems. The general principles outlined under air cooling also apply for liquid cooling. That is, Equation 12 applies, the pressure drop – flow rate relationship is quadratic, and the fan laws also apply. Typical performance of a liquid cooled dissipator is shown in Figure 17.

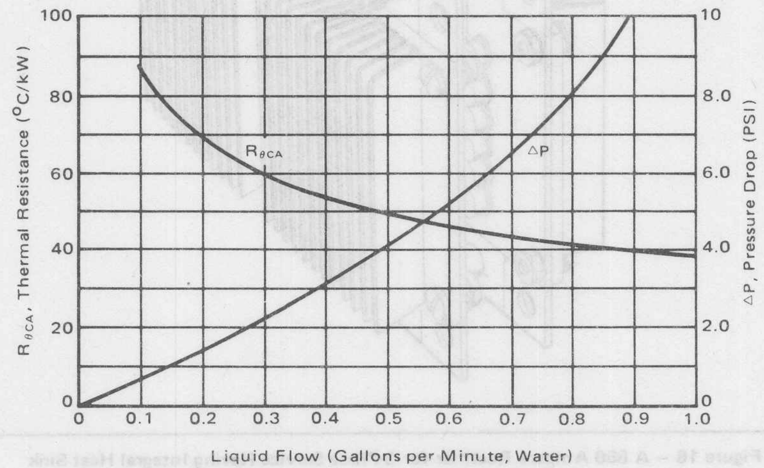


Figure 17 – Typical Performance of a Liquid Cooled Mounting Surface (Courtesy Thermaloy, Inc.)

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CHAPTER 11: RECTIFIER TEST CIRCUITS

The following test circuits are presented to aid the rectifier user in testing, comparing, and troubleshooting rectifier circuits. The test circuits used by Motorola to establish rectifier ratings and characteristics conform to NEMA-EIA standards as defined in NEMA-EIA Publication RS-282* from which the material in this chapter is adapted. Although automated equipment is used at Motorola, the same basic techniques may be applied with any equipment.

When testing rectifiers against specifications, it is essential that the meaning of ratings and characteristics be well understood. "Characteristics" are rectifier parameters which are measured under specified conditions. Characteristics are given as typical data or as maximum or minimum limits. "Ratings" define maximum limits not to be exceeded if long life and high reliability are expected. Ratings are not measured directly, but are established by the judgment of the manufacturer.

ELECTRICAL CHARACTERISTIC TESTS

The following tests are performed by manufacturers to assure compliance to electrical specifications. It is suggested that these tests be employed by users for incoming inspection and evaluation.

Direct-current (Static) Reverse and Forward Characteristics

Reverse characteristic tests are made by applying a direct voltage in the reverse direction to a diode and measuring the flow of the reverse current. Forward characteristic tests are made by passing a given value of direct current in the forward direction and measuring the forward voltage drop. Unless otherwise specified, direct-current measurements are taken after thermal equilibrium is reached because of the temperature sensitivity of characteristics. If any significant power is dissipated, an adequate heat sink must be employed to keep the case temperature at the specified value.

Schematic diagrams of direct-current test circuits are shown in Figures 1 and 2. The supply voltage for reverse current tests should have a current limit, or an external resistor should be placed in series with the supply, to hold fault current to a safe value. To prevent the forward current from drifting because of changes in forward voltage as the rectifier heats, the drop across R in Figure 2 should be at least one volt.

The source of direct current for forward characteristic testing is not considered important providing the ripple is less than 5 percent. In testing the reverse characteristics, the ripple of the voltage source should not exceed 1 percent, and particular care must be taken to prevent voltage transients from exceeding the voltage rating of the diode.

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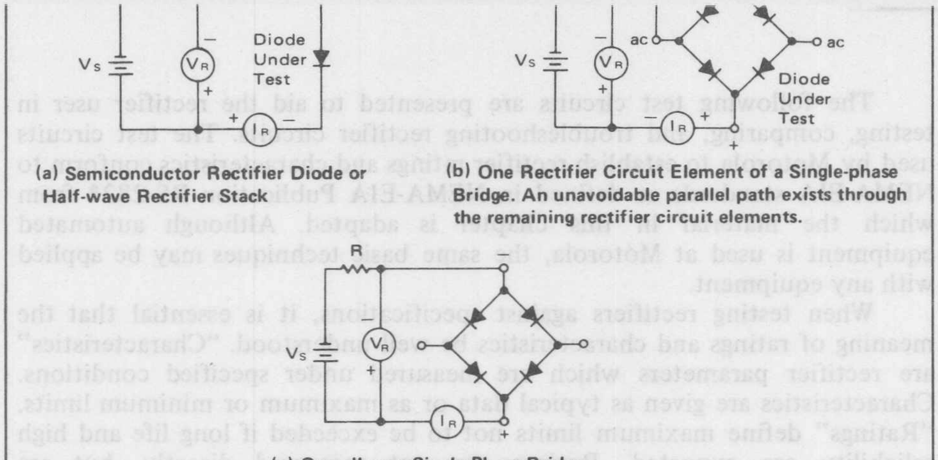
*The information on symbols, thermal resistance, and reverse recovery time is taken from EIA approved material to be included in a forthcoming revision of RS-282

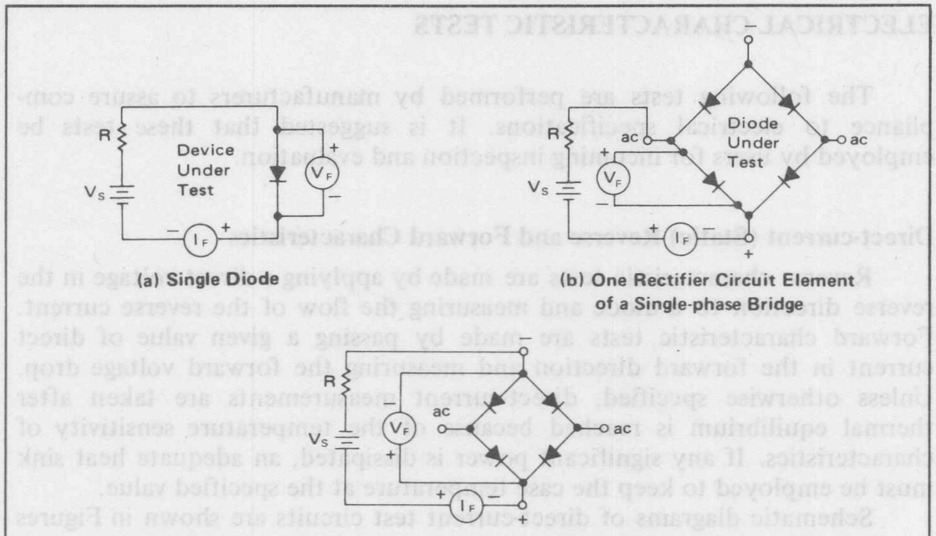


(a) Semiconductor Rectifier Diode or Half-wave Rectifier Stack

(b) One Rectifier Circuit Element of a Single-phase Bridge. An unavoidable parallel path exists through the remaining rectifier circuit elements.

(c) Overall on a Single-Phase Bridge

Figure 1 — Direct-current (Static) Reverse Current Test Circuits



(a) Single Diode

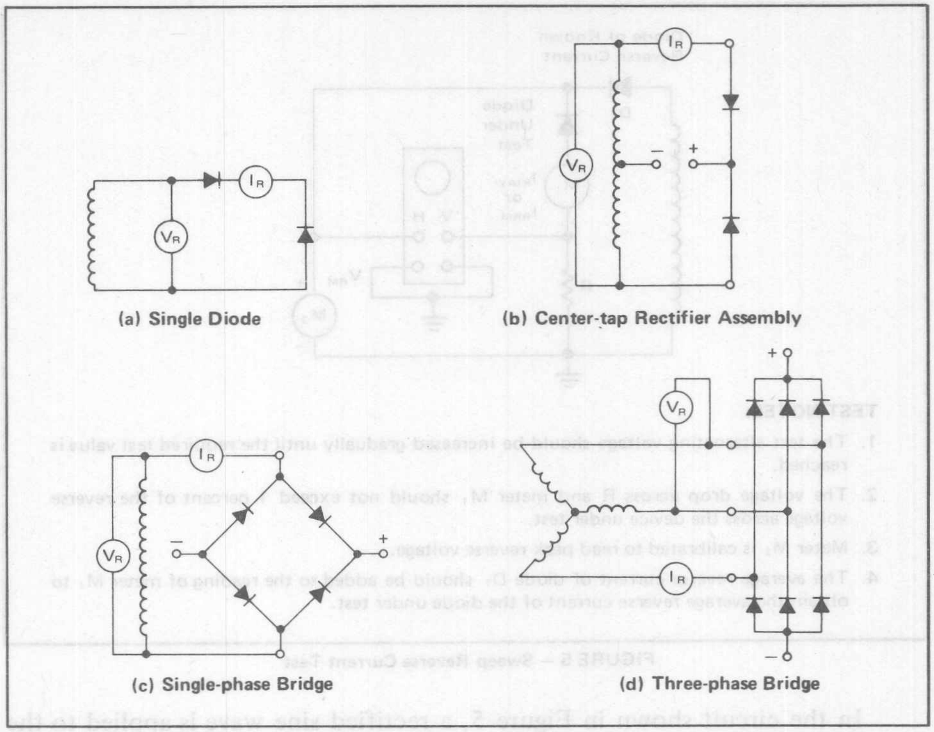
(b) One Rectifier Circuit Element of a Single-phase Bridge

(c) Overall Drop of a Single-phase Bridge

Figure 2 Direct-current (Static) Forward Voltage Tests

Alternating-current (Dynamic) Reverse and Forward Characteristics

These tests are performed with the semiconductor rectifier components connected in the appropriate test circuit and energized with 60-cycle alternating current. Unless otherwise specified, alternating-current measurements should be taken after thermal equilibrium is reached. Measurements may require the use of an attached heat sink as discussed in the previous section. Schematic diagrams of alternating-current test circuits are shown in Figures 3, 4 and 5. The alternating voltage source should be sinusoidal with a total harmonic distortion not exceeding 7 percent of the fundamental.



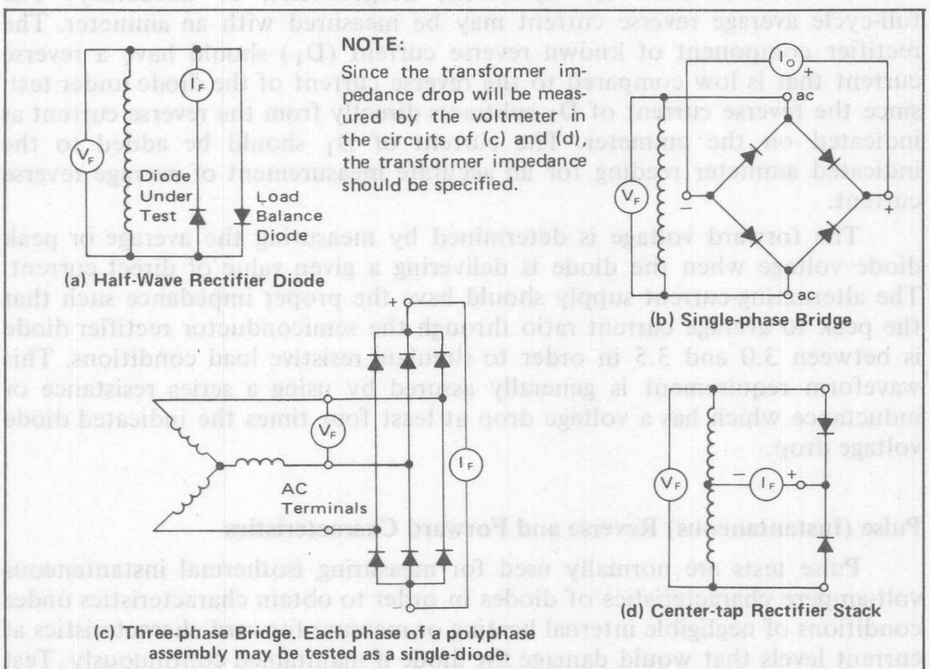
(a) Single Diode

(b) Center-tap Rectifier Assembly

(c) Single-phase Bridge

(d) Three-phase Bridge

Figure 3 – Alternating-current (Dynamic) Reverse Current Tests. The test alternating voltage should be increased gradually until the required test value is reached.



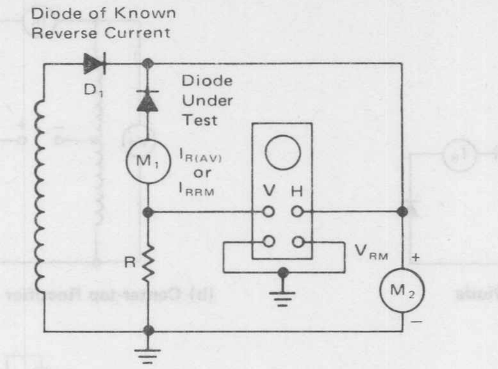
(a) Half-Wave Rectifier Diode

(b) Single-phase Bridge

(c) Three-phase Bridge. Each phase of a polyphase assembly may be tested as a single-diode.

(d) Center-tap Rectifier Stack

Figure 4 – Alternating-current (Dynamic) Forward Voltage Tests. The test as voltage should be increased gradually until the required test current is reached.



TEST NOTES:

1. The test alternating voltage should be increased gradually until the required test value is reached.
2. The voltage drop across R and meter M_1 should not exceed 1 percent of the reverse voltage across the device under test.
3. Meter M_2 is calibrated to read peak reverse voltage.
4. The average reverse current of diode D_1 should be added to the reading of meter M_1 to obtain the average reverse current of the diode under test.

FIGURE 5 – Sweep Reverse Current Test

In the circuit shown in Figure 5, a rectified sine wave is applied to the diode and the reverse current as a function of applied voltage is displayed on an oscilloscope. This method is particularly useful for examining the reverse current characteristics for hysteresis, irregularities, or instability. The full-cycle average reverse current may be measured with an ammeter. The rectifier component of known reverse current (D_1) should have a reverse current that is low compared to the reverse current of the diode under test, since the reverse current of D_1 subtracts directly from the reverse current as indicated on the ammeter. The current of D_1 should be added to the indicated ammeter reading for an accurate measurement of average reverse current.

The forward voltage is determined by measuring the average or peak diode voltage when the diode is delivering a given value of direct current. The alternating-current supply should have the proper impedance such that the peak to average current ratio through the semiconductor rectifier diode is between 3.0 and 3.5 in order to simulate resistive load conditions. This waveform requirement is generally assured by using a series resistance or inductance which has a voltage drop at least four times the indicated diode voltage drop.

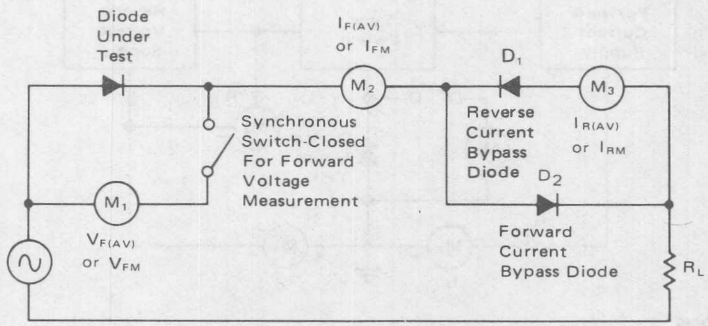
Pulse (Instantaneous) Reverse and Forward Characteristics

Pulse tests are normally used for measuring isothermal instantaneous volt-ampere characteristics of diodes in order to obtain characteristics under conditions of negligible internal heating or measure forward characteristics at current levels that would damage the diode if maintained continuously. Test currents can be obtained by applying a single half-wave from a 60-cycle source to the semiconductor through a suitable switching device. In order to

obtain narrower test pulses with less heating and better control of amplitude, a half-sine wave may be generated by discharging a capacitor through a series inductor with a suitable switching device. Suitable indicating devices for measuring current and voltage values are oscilloscopes, oscillographs, and transient peak voltmeters. The pulses may be applied singularly or repetitively, providing the repetition rate is low enough to limit heating to safe values.

Reverse and Forward Characteristics Under Load

The basic half-wave test circuit shown in Figure 6 may be used to conduct load tests for the purpose of evaluating the quality of semiconductor rectifier components. Suitable precautions should be taken to assure that proper case temperature or ambient temperature conditions have been established and thermal equilibrium attained prior to taking meter readings.



TEST NOTES:

1. Circuits must be devised so that meter M_1 is not subjected to the reverse half cycle.
2. For average readings, meters M_2 and M_3 should be permanent magnet moving-coil-type direct-current instruments.
3. Diode D_1 may be a low-current low-voltage type.
4. Diode D_2 must handle the forward current of the diode under test but its reverse characteristic is unimportant.

Figure 6 — Dynamic Load Test Circuit

Criteria for acceptable load tests circuits are as follows:

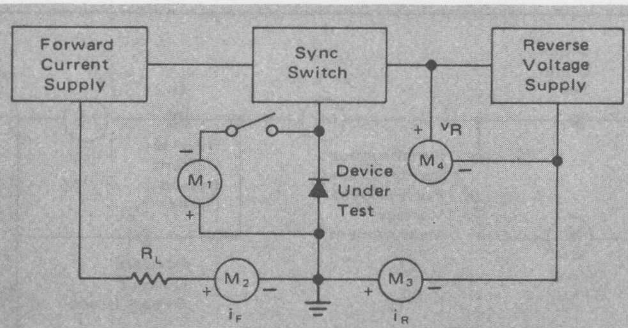
1. Power sources should have sinusoidal waveform.
2. The rated peak value of reverse voltage should be reached during the reverse half cycle.
3. In no case should the forward conduction angle be greater than 180 degrees nor less than 130 degrees. Since the forward power loss may be significantly greater with the 130 degree conduction angle, the manufacturer should be consulted for specific recommendations.

in Figure 7 may be used. The circuit reduces the overall power requirements, yet subjects the rectifier under test to essentially the same operating conditions as Figure 6.

The circuit shown in Figure 7 utilizes two power supplies: a high voltage low current supply for evaluating reverse characteristics, and a low-voltage high-current supply for evaluating forward characteristics. These supplies are switched by means of a synchronous switch (normally diodes are used) at alternate half cycles of the supply frequency and are phased to switch as the forward current or reverse voltage passes through zero.

Surge Current

Surge current tests may be performed using the load test circuits shown in Figures 6 and 7 with proper provisions for increasing the forward current for a specified period of time.



PRECAUTIONS:

1. Meter M_1 should not see reverse voltage half cycles.
2. Meters M_2 and M_3 should be permanent-magnet moving-coil-type direct-current instruments.
3. The load resistor R_L should be large enough to obtain a forward conduction angle of at least 130 degrees.
4. The synchronous switch connects the device under test to the forward current supply during each half-cycle when the polarity of the forward current supply is such that forward current will flow through the device under test. The switch must conduct at least 130 electrical degrees but not more than 180 degrees each cycle. During the alternate half-cycle, the switch is required to support a voltage equal to the peak reverse voltage applied to the device under test. A pair of diodes is normally satisfactory.
5. The reverse voltage supply may consist of an adjustable-voltage transformer with a rectifier diode connected in series with one secondary lead. The polarity of this rectifier diode should be such that no forward current can be supplied to the device under test from the reverse voltage supply. The phasing of the reverse voltage supply transformer should be such that the ungrounded output leads of the forward current and reverse voltage supplies go positive in the same half cycle. The internal impedance of the reverse voltage supply should be low enough to avoid excessive voltage fluctuation and wave-form distortion.
6. Meter M_3 may be replaced with provisions for measuring peak reverse current.
7. The Forward Current Supply consists of an adjustable voltage transformer and a direct-current ammeter to read average direct current flowing through the test rectifier diode. The voltage range of the transformer secondary is determined primarily by the conduction characteristic of the synchronous switch and the size of the load resistor. The rms volt-ampere rating of the transformer secondary should be at least 1.7 times the average dc power drawn by the test rectifier diode, based on a conduction angle of 130 degrees.

Figure 7 — Block Diagram for a Simulated Load Test Circuit

Reverse Recovery Time

A suitable circuit for measuring reverse recovery time is shown in Figure 8. This circuit is designed to simulate the commutation duty encountered in power rectification circuits.

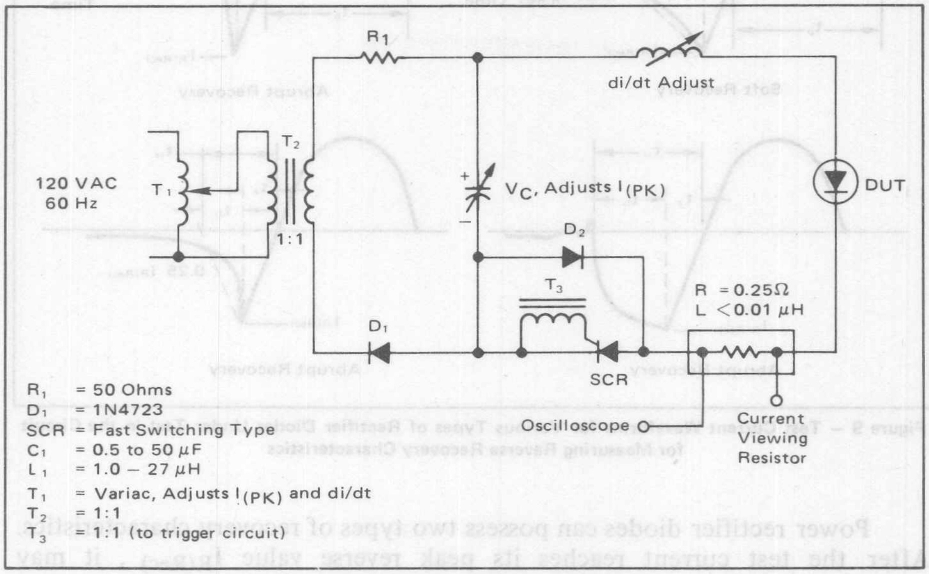


Figure 8 – Recovery Time Test Circuit

The resistance of the power loop is kept very small so that L and C will essentially determine the test current waveform. If this resistance is small, e.g., $2\sqrt{L/C} \gg R$, then the test current will essentially be sinusoidal, possessing a width, $t_P = \pi\sqrt{LC}$, a rate of current change, $di/dt = V_C/L$, and a peak value, $I_{FM} = V_C/\sqrt{L/C}$. V_C is the peak voltage across the capacitor and is as small as practical to achieve the desired test conditions. The effects of reverse voltage magnitude on the test device recovery characteristics are neglected.

The two most important test conditions are the rate of reversal (di/dt) and the magnitude of the test current. No restriction is placed on C, L, V_C or the maximum value of t_P. These may be appropriately adjusted to achieve the desired test current di/dt and magnitude. The restriction on minimum t_P is that it be 5 to 10 times the recovery time t_{rr} of the test device so that the di/dt will be linear and of the same value before and after current reversal.

The inductance of the current viewing resistor must be extremely low, e.g., $< 0.01\ \mu H$. The oscilloscope used to view the current must possess sufficient bandwidth to faithfully reproduce the true current waveform. If certain types of test devices recover too abruptly (see Figure 9), a current oscillation may appear on the oscilloscope following device recovery. This may be reduced by using a lower inductance current viewing resistor and by using a properly terminated oscilloscope connection cable. This oscillation, however, does not have any bearing or effect on the test results. Rectifier diode D_2 and its circuit branch should provide a very low inductance path around the SCR.

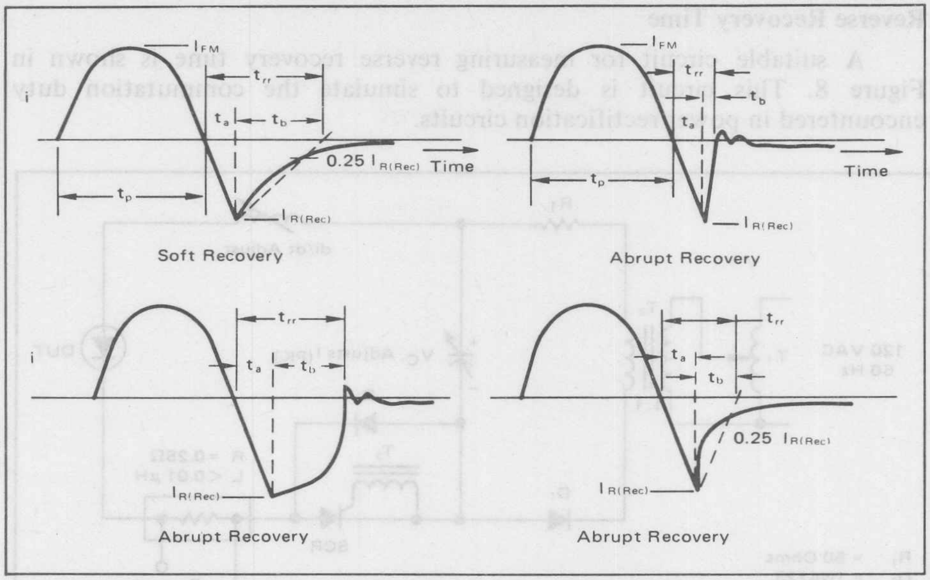


Figure 9 – Test Current Waveforms for Various Types of Rectifier Diodes Under Test in the Circuit for Measuring Reverse Recovery Characteristics

Power rectifier diodes can possess two types of recovery characteristics. After the test current reaches its peak reverse value $I_{R(Rec)}$, it may immediately or a short time later decrease very abruptly (abrupt recovery) or it may decrease slowly and smoothly to its steady-state reverse blocking value (soft recovery). In the former case, the effect of the rapid current change and the loop inductance producing transient voltages across the test device must be considered. The recovery time for rectifier diodes possessing "soft" recovery characteristics is defined as $t_{rr} = t_a + t_b$ (see Fig. 9), where t_a is measured from the instant of current reversal to the instant current reaches its peak reverse value $I_{R(Rec)}$, and t_b is measured from $I_{R(Rec)}$ to the instant the straight line connecting $I_{R(Rec)}$ and $0.25\ I_{R(Rec)}$ intercepts the zero current axis. The recovery time for devices possessing abrupt recovery characteristics is defined in the same manner except t_b is measured to the instant the test current waveform apparently intercepts the zero current axis. Note that the shape of the recovery characteristics can be fairly well determined if the value of t_b is compared to that of t_a. It is for this reason that the recovery characterization is done in this manner. Note that for go-no-go reverse recovery testing, limit points $I_{R(Rec)}$ and $0.25\ I_{R(Rec)}$ should be based upon the registered $I_{R(Rec)}$ maximum value.

The recovered charge (Q_R) of the test device is defined as the area under the reverse current-time curve. It may be measured by some integration (graphical or electronic) process if the beginning and ending time points for the integration are defined. Generally the starting point is at the instant of current reversal and the ending point is at some specified reverse current.

Junction Capacitance

The capacitance of a rectifier diode is dependent on bias level, polarity,

and to a minor extent, frequency. An arbitrary choice of these conditions may be made to provide the necessary standardization between the user's and the manufacturer's testing procedure. The capacitance is normally measured under reverse bias conditions and is given in terms of an equivalent parallel circuit capacitance.

The bias supply should be properly isolated from the capacitance measuring equipment or have negligibly low capacitance. Also, the peak-to-peak alternating-current signal from the measuring equipment should be small in comparison to bias levels to prevent self-biasing of the diode and to minimize other errors due to "large signal" effects.

THERMAL RESISTANCE

The thermal resistance (R_θ) of a semiconductor device is a measure of the ability of its mechanical structure to provide for heat removal from the active semiconductor element and, therefore, it is an indication of power handling ability. One dimensional heat flow is assumed in thermal resistance specifications which must always include the two points between which the thermal resistance value applies. Two of the most common thermal resistance specifications are:

1. Thermal resistance between the junction and a specified point on the case of the device.
2. Thermal resistance between the junction and the ambient. Sometimes a heat dissipator is attached to the rectifier diode.

Test Description

Since junction temperature cannot be directly measured, a temperature sensitive device parameter is used as its indicator. Forward voltage at a small percent of rated current is the recommended parameter to use. The value of the low level current used is called metering current $I_{F(Met)}$ and the resulting diode voltage is called metering voltage $V_{F(Met)}$.

The determination of junction to case thermal resistance, ($R_{\theta JC}$) consists of making measurements to satisfy the following equation:

$$R_{\theta JC} = \frac{T_J - T_C}{P_{(AV)}} = \frac{T_{C1} - T_{C2}}{V_{F(Htg)} \times I_{F(Htg)} \times \text{Duty Factor}}$$

where: T_{C1} = measured case temperature with only metering current flowing. Under this condition $T_J = T_{C1}$. The case temperature is adjusted by the external application of heat to produce a value of low level forward voltage (called metering voltage) which is equal to that obtained when the device is operated with power applied.

T_{C2} = measured case temperature when the diode is mounted to a heat dissipator and operated with applied power.

$I_{F(Htg)}$ = heating current used to produce the power dissipated in the semiconductor die.

$V_{F(Htg)}$ = forward voltage when $I_{F(Htg)}$ is applied.

junction-to-ambient thermal resistance, $R_{\theta JA}$, substitute ambient temperature T_A for T_{C2}.

The test procedure consist of two distinct steps: 1) a Power Application Test and 2) a Calibration Test.

In Step 1 the device is operated with power intermittently applied at a very high duty cycle. During the intervals between power pulses, the metering voltage is measured. The current and voltage waveforms are shown in Figure 10. Normally the repetition rate is 60 Hz, but for testing very high current devices, a slower repetition rate may be required. The metering current, which flows continuously, must be held constant during the metering interval between power pulses when the test device impedance is varying considerably. To obtain maximum junction temperature, it is necessary to read $V_{F(Met)}$ at the exact instant when the heating current removal is initiated. However, this is not possible. First a finite time is required for the forward current to decay from the heating current value to the metering current value ($t_2 - t_1$ in Fig. 10). The rate of forward current decay is a factor and must be listed as a test condition. Secondly, transients will exist in the metering voltage waveform for some time after the metering current value is reached because of charge storage effects. Thirdly, induced voltage due to the reduction in forward current may also cause some voltage waveform distortion. Consequently the metering voltage cannot be used as an indicator of junction temperature until after these transients subside. The time t_3 on the waveforms represents the shortest time after removal of heating current that metering voltage may be measured. For a particular device type, the time t_3 may be found by performing the test at various power levels and noting the shortest time where the measured value of thermal resistance is essentially independent of the power dissipated. Power levels of 25% above and below the power corresponding to the specified heating current are recommended for this determination. Time t_3 should be expected to be in the range of 100 to 200 microseconds for standard recovery diodes.

Since some die cooling occurs between the time when the heating current changes (t_1) and time t_3, the thermal resistance value determined from a metering voltage measurement at t_3 will be in error. It is therefore necessary to extrapolate the metering voltage waveform back to t_1 from t_3 based on the shape of the waveform from t_3 to t_4. Linear extrapolation of the actual cooling curve from time t_3 back to time t_1 results in little error. Figure 10c illustrates the extrapolation.

It is recommended that the thermal resistance test be performed so that the test device junction temperature is within 80% of its rated value. The size of the heat sink used for the power application test must be chosen appropriately. The approximate case temperature (T_{C2}) at which the device must be operated can be determined from the basic thermal resistance equation given at the beginning of this section. The recommended type of heat sink for the junction-to-case thermal resistance test is a flat plate with the test device centrally mounted. Mounting procedures are discussed in Chapter 10. The top terminal connection should be such that heat dissipated does not add to the junction temperature of the test device. For solder terminal devices, it is recommended that the wire size used be the largest size

that will fit through the hole in the terminal. Devices with flexible top leads should have the lead bolted to a heavy copper bus bar. There should be no forced air cooling of the diode case, lead, or top terminal.

In addition to the measurement of the metering voltage waveform, the heating current $I_{F(Htg)}$, heating voltage $V_{F(Htg)}$, and the case temperature T_{C2} are all to be recorded during Step 1.

The power application test (step 1) produced a value of forward voltage at the metering current level which corresponded to the maximum junction

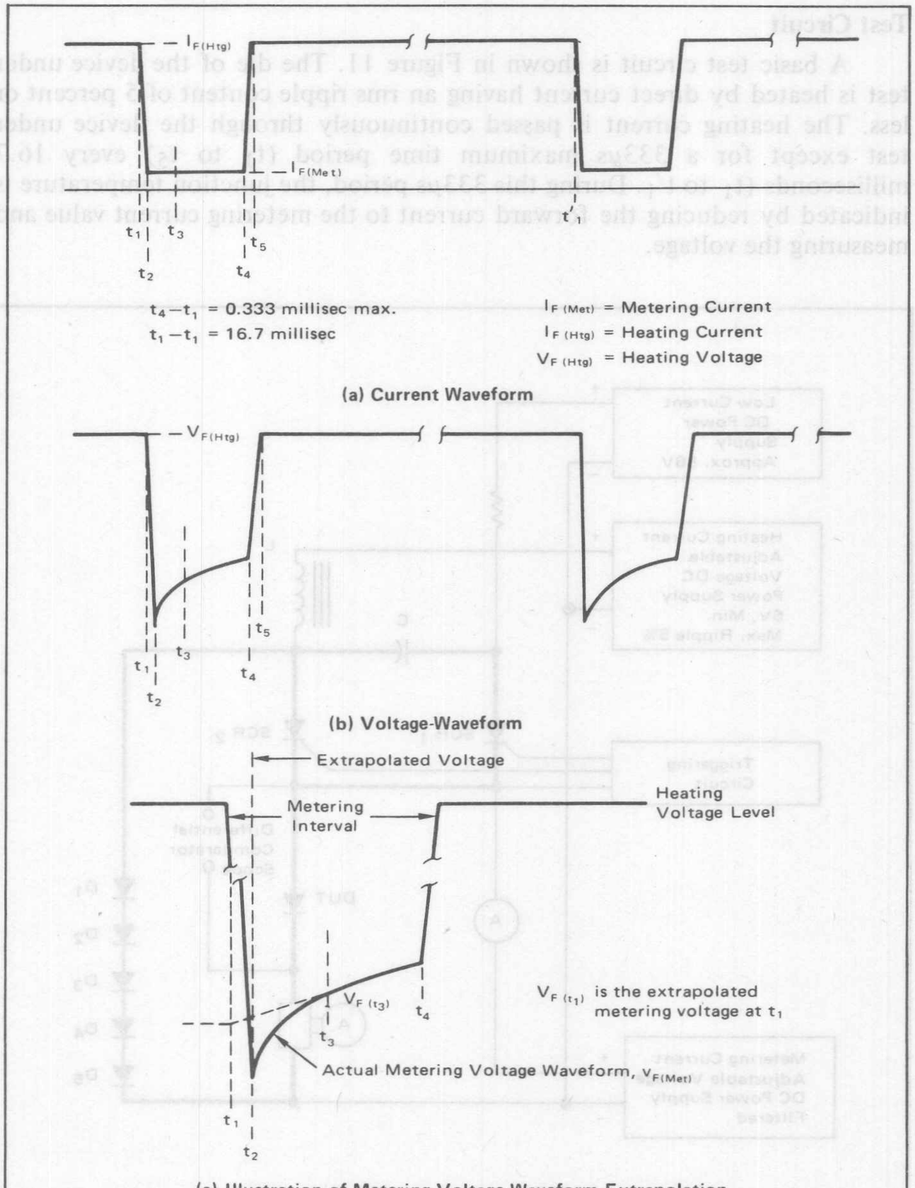


Figure 10 – Current and Voltage Waveforms During Thermal Resistance Test.

temperature attained. Step 2 consists of operating the test device with no significant power dissipation so that for all practical purposes the junction temperature and case temperature will be equal. At the same value of metering current as in Step 1, the forward voltage is monitored and the diode is externally heated on a temperature controlled block or in an oven until the measured value of voltage equals the extrapolated value $V_{F(t1)}$. When the on-state voltage has stabilized, the case temperature (T_{C1}) is recorded.

Test Circuit

A basic test circuit is shown in Figure 11. The die of the device under test is heated by direct current having an rms ripple content of 5 percent or less. The heating current is passed continuously through the device under test except for a 333μs maximum time period (t_1 to t_5) every 16.7 milliseconds (t_1 to t'_1. During this 333μs period, the junction temperature is indicated by reducing the forward current to the metering current value and measuring the voltage.

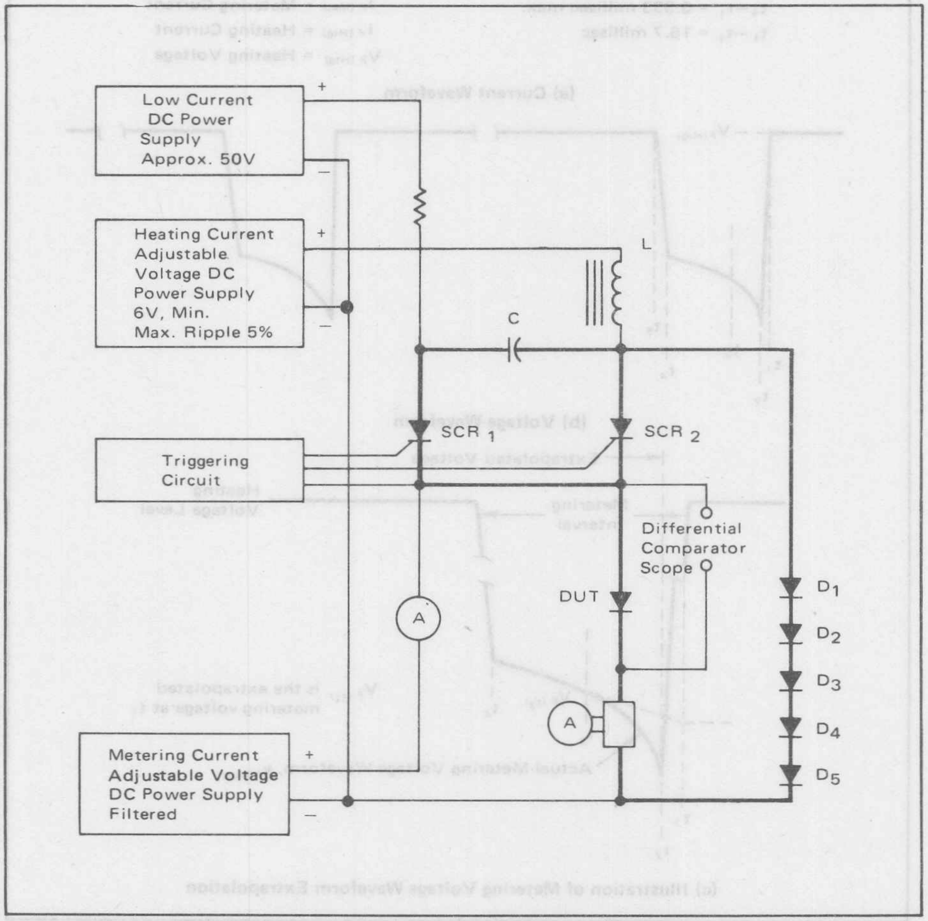


Figure 11 — Basic Thermal Resistance Test Circuit.

Control of the heating current through the device under test is accomplished by SCR_1 and SCR_2 which function as a dc flip-flop switching at a 60 Hertz repetition rate. Current is carried by SCR_1 only during the metering interval so SCR_1 may be considerably smaller than SCR_2. C, which is charged by the low current dc power supply, has the function of turning off SCR_2 when SCR_1 is triggered.

Unavoidable inductance in the heating current power supply and associated circuit wiring make it impossible to turn off the heating current abruptly without creating transient voltages which would interfere with the measurement of on-state voltage. To overcome this problem, a diverter circuit consisting of rectifier diodes D_1 through D_5 is included so that heating current is not interrupted by SCR_2, but is simply switched to a different path. The inductor L may be included to make certain that the heating current does not vary while it is being switched from one path to the other. This inductor also serves to reduce an undesired flow of current from C through the device under test and the heating current power supply. The lead inductance in the diverter circuit should be kept low so that 10 microseconds after SCR_1 begins to conduct all heating current will have been diverted away from the device under test. In Figure 11 the portion of the circuit in which inductance must be carefully controlled is indicated by heavy lines.

In order to accurately observe the forward voltage of the test device during the metering current interval, the use of a differential comparator oscilloscope preamp with a solid-state main frame amplifier is recommended. With care this equipment should allow magnification of the on-state voltage waveform during the metering current interval without distortion or zero shift being introduced due to the presence of the heating voltage waveform. An oscilloscope camera is extremely useful for recording the waveform so that the photos can be used to obtain the data for the necessary extrapolation of the metering voltage waveform.

LIFE TESTS

Life tests may be conducted for the purpose of determining the extended time-performance characteristics of semiconductor rectifier components. Tests are performed to detect problems which might arise during field operation.

Stud- or base-mounted rectifier diodes require attention to the mounting procedure in order to minimize the interface thermal resistance as discussed in Chapter 10. The temperature reference point is at a specified place on the case.

Lead-mounted rectifier diodes are tested in the same manner as stud- or base-mounted units but attention must be given to the mounting conditions. It is recommended that the diodes be mounted with a minimum lead length between the mounting and body of 3/8 inch and with a maximum lead length between the mounting and the body of 1/2 inch. In those instances where the body of the diode includes tubulations, these dimensions shall be considered as applying between the end of the tubulation and the mounting.

The mountings shall be maintained at a temperature greater than or equal to the specified ambient air temperature. If lead temperature is specified, it must be maintained at the rated value (+10°C, –0°C).

Steady-state Operation

The diode to be life-tested shall be subjected to the steady-state operational life test under the following conditions:

1. Rated I_O at registered $T_C \pm 5°C$ with a conduction angle at or between 130 and 180 degrees.
2. Rated V_{RWM}.
3. 60 Hz test power frequency.
4. 1000 hour test duration.
5. End-point readings made at least at 1000 hours (+72 hours, −24 hours).

Initial and end-point limits shall be as agreed to by the user and manufacturer. Test readings shall consist of the following:

1. Reverse Current Test (I_R) (See Figure 1).
   a. V_R at T_C as registered. (±3°C)
   b. An adjustable direct current voltage shall be applied to the rectifier diode under test by increasing the voltage from zero to the rated dc reverse voltage V_R.
2. Forward Voltage Test (V_F) (See Figure 2).
   a. I_F (amperes direct current) = I_O (amperes average) at T_C as registered.
   b. V_F must be read within 2 seconds after the application of I_F.

Intermittent Operation

The rectifier diode to be life-tested shall be subjected to the intermittent operational life-test as outlined in Figure 12 under the following conditions.

1. Adjust electrical conditions as described above for a steady-state life test.
2. Removal of reverse power during the off power period shall be optional.
3. The case temperature of the rectifier diode under test shall start at a temperature between 20°C and 50°C, when each power period is applied, and rise to a maximum temperature of registered T_C @ I_O. The registration format provides for a +10°C to −0°C tolerance window for T_C. The case temperature of the rectifier diode shall remain at this maximum temperature for the remainder of the applied power period. The cooling-off period shall return the case temperature of the rectifier diode to the original starting case temperature. The entire intermittent cycle is shown in Figure 12.

Test duration, initial and end-point test readings, and their time interval shall be the same as for the steady-state tests.

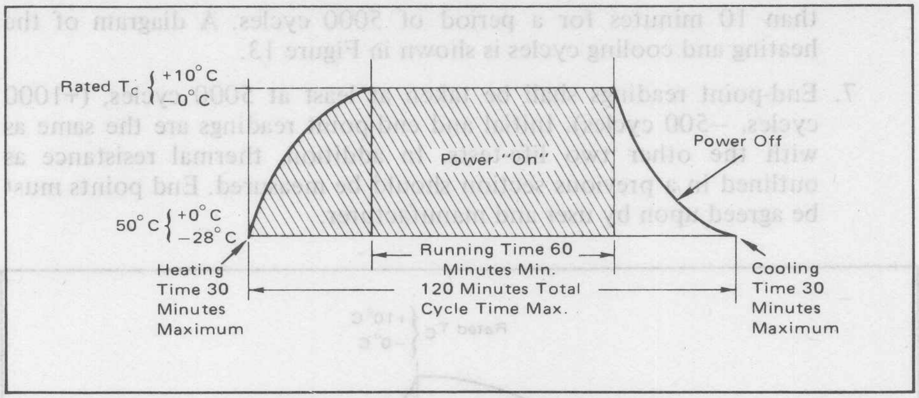


Figure 12 – Intermittent Cycle for Life Tests

Thermal Fatigue

The diode shall be subjected to the thermal fatigue life test under the following conditions:

1. The diode to be life-tested shall be placed on an adjustable heat fin or temperature-controlled heat sink. Caution should be exercised in this life-test method when adjustable heat fins are being used in conjunction with life-test equipment that utilizes a series-string method of test circuitry. Two controls which can be used are:

   a. If one size plate or fin is to be used for a number of devices, the thermal resistance of the devices to be tested must be kept within limits so that over-or under-heating of the junctions will not occur.

   b. If the thermal resistance of each device is not controlled, each individual heat fin must be trimmed to give the proper temperature excursions on the case of the diodes.

2. Rated I_O (conduction between 130 and 180° at 60 Hz) at specified T_C shall be applied for a period of not less than 2 and not more than 6 minutes. During this time, the case, which is initially at some temperature between 20° and 40°C, will be driven by either internal power loss (when mounted on a heat fin) or a controlled heat sink (which combines external and internal power for heating) to a case temperature of registered T_C + 10°C, −0°C.
3. No reverse voltage shall be applied during the heating period.
4. After the heating period, the current shall be turned off, and a cooling cycle of not more than 8 minutes maximum will start. Cooling shall be done by any convenient method (forced air, fluid-cooled heat sinks, fins, etc.). A case temperature of from 20°C minimum to 40°C maximum shall be reached by the end of the cooling cycle.
5. No reverse voltage shall be applied during the cooling period.
6. The life test shall be operated over a thermal cycle time not longer

than 10 minutes for a period of 5000 cycles. A diagram of the heating and cooling cycles is shown in Figure 13.

7. End-point readings shall be taken at least at 5000 cycles, (+1000 cycles, −500 cycles). Initial and end-point readings are the same as with the other two life-tests. In addition, thermal resistance as outlined in a previous section should be measured. End points must be agreed upon by user and manufacturer.

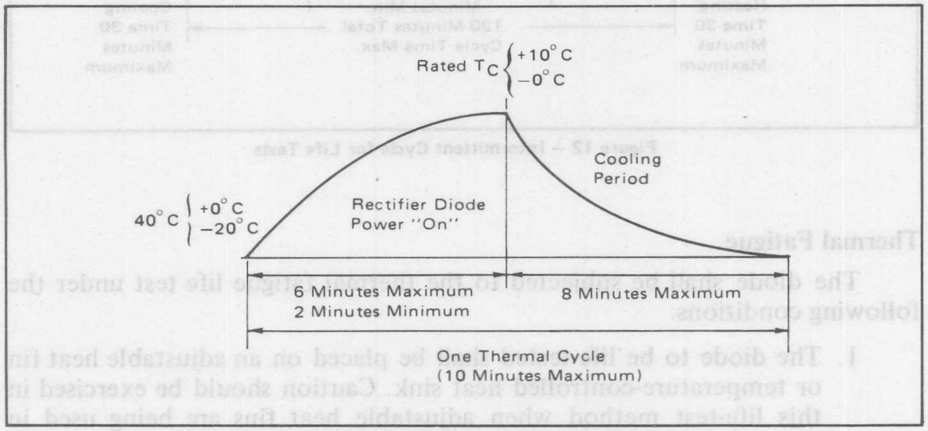


Figure 13 – Heating and Cooling Cycles for Thermal Fatigue Tests

Simulated Life-Test Circuit

When life tests require the use of large quantities of power, due to the size of the rectifier diode being tested or the number of units on test, it becomes necessary to develop a simulated circuit which will reduce the power used and, at the same time, subject the rectifier to the same operating conditions as it would see in a normal life-test circuit. A system for testing a number of diodes from one supply is shown in Figure 14. Simulated tests are described in the previous section. Special precautions when performing life tests on rectifier banks follow:

1. A fuse or circuit breaker should be used in series with each test rectifier diode to isolate defective diodes without interrupting the test. An alternate protection method is the use of a single fuse or circuit breaker connected in series with the ungrounded output lead of the reverse voltage supply. With this method, failure of a single cell removes reverse voltage from all test rectifier diodes. If the reverse voltage supply has limited power capacity so that it cannot furnish enough current to blow the fuse, yet it may be damaged by a short circuit, a dual supply system is required. An auxiliary low-voltage low-impedance supply, isolated by a blocking rectifier diode, may be connected in parallel with the reverse supply to furnish the fault current required to operate the protective device.
2. A load resistor is required in series with each test rectifier diode. This resistor shall be large enough to insure accurate current division between test rectifier diodes. The voltage drop across this resistor shall also be high enough to permit a conduction angle of at least

130 degrees. The power dissipated in this resistor is 2.9 times the product of resistance and average current squared.

3. The rectifier diodes to be life-tested shall be operated at rated average current when mounted on a suitable heat sink to maintain rated stud temperature.

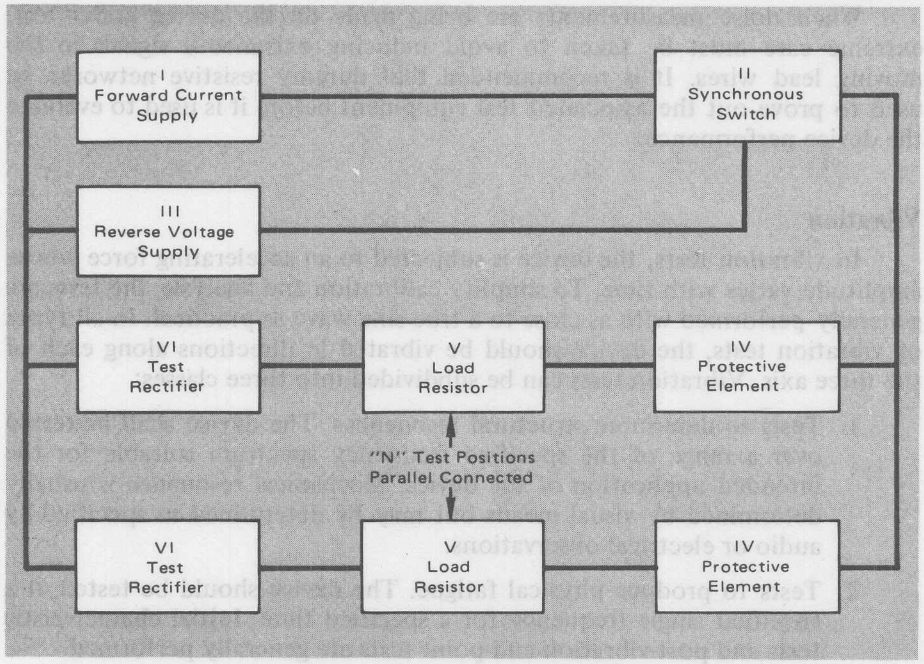


Figure 14 — Block Diagram, Simulated Life-Test Circuit

ENVIRONMENTAL TESTS

Environmental tests are performed to obtain physical or electrical data resulting from or occurring during conditions of shock, vibration, temperature, humidity, or other environmental phenomena. These tests are generally used to evaluate ratings, to compare similar devices, to study characteristics, or to determine performance relative to a specific application. The electrical tests performed on the semiconductor rectifier component fall into two classes:

1. Initial characteristic tests prior to environmental tests and post-environmental end-point tests.

2. Tests made during a specific environmental condition.

Shock

In shock tests, the device is subjected to a specified unidirectional acceleration for a specified time. To evaluate the effect of shock on the device, it is usually necessary to transmit the shock to the device along at least one axis. The direction of the axis must be specified for each device configuration.

The jig used to hold the device under test should be designed to exert the least possible pressure. Care must also be taken to limit the amount of cushioning material employed in the jig since the shock transmission characteristic of these materials is poor. Under conditions of high short-term acceleration, even metals such as steel, must be regarded as highly viscous fluids.

When noise measurements are being made on the device under test, extreme care must be taken to avoid inducing extraneous signals in the moving lead wires. It is recommended that dummy resistive networks be used to prove out the associated test equipment before it is used to evaluate the device performance.

Vibration

In vibration tests, the device is subjected to an accelerating force whose amplitude varies with time. To simplify calibration and analysis, the tests are generally performed with as close to a true sine wave as practical. In all types of vibration tests, the device should be vibrated in directions along each of the three axis. Vibration tests can be subdivided into three classes:

1. Tests to determine structural resonances. The device shall be tested over a range of the specified frequency spectrum suitable for the intended application of the device. Mechanical resonance is usually determined by visual means but may be determined as specified by audio or electrical observations.

2. Tests to produce physical fatigue. The device should be tested at a specified single frequency for a specified time. Initial characteristic tests and post-vibration end-point tests are generally performed.

3. Tests to evaluate performance under vibration and electrical operating conditions. The device is usually tested at a single vibration frequency of sufficient amplitude to evaluate the performance under specified electrical operating conditions. Noise output and parameter shift are both used to evaluate performance

Acceleration

Acceleration tests subject the device to a short-duration high-centrifugal acceleration. The device under test is commonly mounted in a semicompliant material (e.g., nylon, teflon, etc.) to prevent excessive stresses from being generated at any point on the case or encapsulation, unless the application indicates other requirements. Initial characteristic tests and post-acceleration end-point tests are generally performed.

Humidity

The resistance to moisture penetration is primarily a function of the encapsulation or protective coating. The device under test is subjected to specified relative humidity and temperature conditions for specified periods of time and, then, is generally allowed to dry following removal from the test condition. Initial characteristic tests and post-humidity end-point tests are generally performed.

Salt Atmosphere

In salt atmosphere (or salt spray tests), the device is subjected to a specified condition for a specified time to determine the susceptibility of the device to corrosive atmospheres. The device is generally washed and dried after removal from test conditions. Initial characteristic tests and post-salt-spray end-point tests are generally performed.

MECHANICAL TESTS

The following mechanical tests may be performed to determine if the degree of mechanical ruggedness is adequate to withstand normal installation requirements. The manufacturer of the specific device should be consulted for test conditions. Diodes subjected to these test are normally considered unsuitable for further use.

Lead Fatigue

This test may be performed on lead-mounted rectifier diodes by bending each lead through the specified angle the specified number of times in a cyclical manner. All arcs on a single lead are made in the same plane without torsion. Failure is defined as lead breakage.

Lead Pull

This test may be performed on lead-mounted semiconductor rectifier diodes by applying the specified force, without shock, to the lead either parallel or perpendicular to the axis of the device. Failure is defined as lead breakage.

Torque

This test may be applied, where applicable, by applying the specified torque between the terminal and the case. The manufacturer's recommendations for means of clamping the device should be followed. For stud-mounted devices, the torque should be applied between a specified mounting nut and the case. The manufacturer should be consulted for recommended mounting procedure or for recommendations regarding use of thread lubricants.

Thermal Shock

This test may be performed on semi-conductor rectifier diodes which are hermetically sealed. The test is performed by immersion of the device in a suitable liquid at elevated temperature for not less than 15 seconds and, immediately thereafter, in a suitable liquid at low temperature for not less than 5 seconds. The volume of liquid should be large enough to prevent a temperature change of more than 5°C upon immersion. The manufacturer should be consulted for recommended values of high and low temperature.

Dielectric Strength

A rectifier assembly or a device having an isolated case should be capable of withstanding a specified potential for a specified period of time between current carrying parts and non-current carrying metal parts, which may be grounded.

Starting at zero, the applied potential should be increased gradually until the required test value is reached or breakdown occurs. All device terminals should be connected together before the potential is applied. The manufacturer should be consulted for specific test conditions.

CHAPTER 12: RELIABILITY CONSIDERATIONS FOR THE CIRCUIT DESIGNER

The ultimate goal of a circuit designer is to produce circuits, which when assembled into a system, will enable the equipment to perform its intended function with less than a defined percentage of "down time" due to equipment malfunction. To do this, the designer must have a knowledge of all facets of reliability which contribute to system reliability, some of which are:

(1) The relationship of component reliability to system reliability.

(2) The causes of component failure.

(3) How reliability is measured.

(4) The various methods of specifying reliability assurance.

(5) The factors involved in selecting components.

(6) The effect of circuit design upon overall system reliability.

These facets of reliability, as pertaining to rectifiers, will be discussed in this chapter. In a general way, much of the discussion can be applied to other components as well.

RELIABILITY OF SOLID-STATE SYSTEMS

The ultimate measure of reliability is the degree to which a system performs the function for which it was designed. A general method of expressing system reliability is Mean Time Between Failures (MTBF), which is equal to operating time divided by the number of failures. A number of other measures of system reliability are used, but MTBF is probably the most commonly accepted, and can be related to the others mathematically. The reciprocal of MTBF is the failure rate. The MTBF of a system is, of course, dependent upon the number of components used in the system as well as the reliability of the individual components under the stresses encountered. In comparing reliability of different systems, a useful method of normalizing is to consider failures per component hours. This is the number of failures divided by the product of the number of components and the hours of system operation.

The MTBF for a system is not a constant over its entire life. The MTBF will probably be relatively short during the "debugging" phase early in a system's life, until the early life failures due to both component manufacturing and system assembly faults are eliminated, and late in life when the failure rate increases due to component wear-out failures. During the midportion of life, when the failures are random in nature, MTBF should be a maximum.

Reliability is usually expressed as failure rate in percent per 1000 hours. Since failure rate is the reciprocal of MTBF, it is also possible to express diode failure rates in terms of MTBF, but such an expression can be

extremely misleading. For example, failure rates on the order of 1.0% to 0.1% for 1000 hours of life testing at maximum rated conditions are available from the semiconductor industry today. A failure rate of 0.1%/1000 hours is equivalent to an MTBF of 1,000,000 hours or over 114 years.

However, this is a rather meaningless figure for a number of reasons, some of which will be discussed in the following sections. All rectifier reliability will, therefore, be expressed in terms of failure rate throughout this chapter.

ACHIEVING RELIABILITY

Three major factors contribute to reliability:

(1) Basic device design.

(2) Manufacturing processes.

(3) Quality and Reliability Control.

Device Design

The reliability of a rectifier is fundamentally dependent upon the device design. Regardless of the degree of effort placed into device screening and circuit designing, the ultimate reliability obtained from a rectifier in actual application can be no greater than that provided inherently by the design. Therefore, reliability must be considered at the design and process development stages to establish a firm foundation for a comprehensive reliability program.

Designing for reliability entails defining all stress factors in the application under which the device must operate. The device must be targeted to specific power and temperature ratings and to mechanical environments. The design must then be evaluated by thorough reliability testing, and the results supplied to the design engineering department. This closed-loop feedback procedure provides valuable information necessary to cause corrective action on such important design features as electrical stability due to surface effects, mechanical strength, and thermal resistance.

Manufacturing Processes

This closed-loop feedback method of designing-out known failure modes is actually coupled with standardization of manufacturing processes since both are established by the design engineering department. As a product line matures in reliability, it is accompanied by increase in manufacturing yield due to advancing technology and refinement of the manufacturing processes. Therefore, the by-product of a well-designed reliability effort is profitable to both manufacturer and user, since operational cost reductions allow reliable products at a lower price. This enables the manufacturer to remain competitive in a market demanding increased reliability as the technology develops.

Quality and Reliability Control

In order to provide the design engineering department with the necessary input for upgrading manufacturing processes and techniques, a stringent system of process control must be instituted. This system of process control involves two functions within Reliability and Quality Assurance, an in-process Q.C. group with the expressed function of monitoring quality of material and workmanship at each stage in the manufacturing of the rectifier, and a reliability test group for testing the finished product.

There are many variables that must be controlled to produce a reliable rectifier, and the in-process Q.C. group is charged with the task of controlling the larger percentage of these variables. Strict controls are placed on all aspects of manufacturing from materials procurement to the finished product. Included in this broad spectrum of controls are:

(1) Materials Control

All material, purchased or fabricated in-plant, are closely checked against rigid specifications. A constant quality rating on vendors is kept up-to-date to insure that only materials of a proven quality level will be purchased.

(2) In-Process Inspection and Control

Numerous inspection stations maintain a statistical Quality Control program on specific manufacturing processes or parameter classification steps. If these processes are found to be in an out-of-control condition, the discrepant material is diverted from the normal production flow, and the cognizant design engineer notified. Corrective action will be instigated to remedy the cause of the discrepancy and, thus, may entail a design change.

(3) Reliability Testing

Reliability testing includes lot acceptance testing, such as, elevated temperature operation, life, surge-current capability tests, and hermetic-seal tests. Documentation and transfer of the results of these tests to the design engineer is the responsibility of the Quality Control group.

CAUSES OF FAILURE

A knowledge of the causes of semiconductor device failure is essential to an understanding of reliability. Since a complete analysis of semiconductor device failure mechanisms is beyond the scope of this chapter, only the most general aspects of failure mechanisms will be considered.

Rectifier failure mechanisms can be broadly classified as follows:

(1) Surface Defects

(2) Mechanical Defects

(3) Bulk Defects.

Surface Defects: The most prevalent cause of poor reliability is failure due to the condition of the semiconductor surface. A surface condition

leading to poor reliability may be caused either directly by imperfections within the encapsulated rectifier itself, or by failure of the package which causes the semiconductor surface to be subjected to the external environment, or a combination of both these factors. During fabrication, every precaution is taken to assure stability of semiconductor surfaces. This is particularly true for the fabrication steps just prior to encapsulation.

Such techniques as – (1) the encapsulation of the diodes in an inert atmosphere (such as nitrogen) to reduce possibility of chemical reaction with the semiconductor surface, (2) the use of getters which absorb moisture to maintain low partial vapor pressure within the package, and, (3) the use of junction passivation – are all designed to stabilize or to isolate the semiconductor surface from the surrounding environment.

Stresses which cause a change in the state of the semiconductor surface during life are a potential source of poor reliability. Among the factors which can introduce mechanisms to change the state of the rectifier surface are:

(1) Entrapment of moisture or other contaminants within the package during encapsulation.

(2) Loss of the hermetic seal due to improper encapsulation, i.e., leaks which were present at the time the rectifier was manufactured or which occurred during subsequent life.

Surface defects are most often detected by reverse current (I_R) instability over periods of life stressing. Fabrication techniques are not identical for all device types, and these differences can create different levels of I_R between the device types. The magnitude of I_R therefore becomes significant only when compared with the mean I_R for that device.

Mechanical Defects: The mechanical defects which can occur in diodes are relatively easy to analyze. Among these are:

(1) Poor bonding of die-to-header

(2) Poor lead-to-die contact

(3) Lack of hermetic seal.

Poor contact of the die to the header may increase the thermal resistance of the rectifier, resulting in high junction temperatures during high power operation. Poor contacts may also cause hot spots, but this is of secondary importance for relatively low level applications.

Bulk Defects: Bulk defects in rectifiers are generally a less frequent cause of poor reliability than surface or mechanical defects. Bulk defects are often difficult to detect by in-process controls during the fabrication process, although they are usually detected at the final electrical test.

Included in this classification of defects are crystal imperfections which can cause non-uniform diffusion, (resulting in high current concentrations and hot spots), and undesired impurities which can result in uneven voltage gradients. These uneven voltage gradients can cause, in a worst case, failure due to punch-through. A second class of bulk defects results from diffusion of impurities and metal contacts into the bulk material at normal operating temperatures. This problem is generally minimized in a well-designed and fabricated rectifier.

Failure Analysis: Complete rectifier failure analysis is quite complex; it requires extensive facilities and a thorough knowledge of semiconductor theory and fabrication methods. However, preliminary analysis at the equipment manufacturer's plant can prove very helpful in improving the reliability of solid state systems.

When a failure is detected at any stage of systems manufacture–from incoming parts inspection to final systems test–a complete record should be compiled describing the indication of failure, the stage of manufacture at which the failure occurred, the circuit in which the diode failed, the stress applied, and any other information which might help complete the history of the failure. When the rectifier is returned to the analysis laboratory, it should be visually examined for any possible indication of mishandling. Then it should be measured for electrical characteristics to determine if it truly is a failure.

If an electrical test indicates the rectifier is inoperative, the failure may be mechanical in nature and the device should be X-rayed in an attempt to see the cause of failure before the diode is cut open. Opening a rectifier case should be the last operation in failure analysis, because no matter how much care is exercised, additional damage may be done which may mask the original cause of failure. Once the rectifier is opened, the cause of mechanical failure will usually become apparent under microscopic examination.

If, when tested, the rectifier shows little or no deviation from specification, it is well to observe its characteristics on a curve tracer where any irregularity in characteristic curves will be apparent. The rectifier should be trapped while its characteristics are being observed to detect any intermittent condition.

If the rectifier shows excessive leakage, the case should be thoroughly washed to remove any conductive paths that have formed externally.

The investigation may be carried further by increasing and decreasing the rectifier temperature to the limits of the rectifier rating, while observing the device characteristics on a curve tracer for irregularities.

With the possible addition of a leak detection test, this is probably as far as failure analysis can be practically carried outside of a semiconductor laboratory, and even for this preliminary analysis, thoroughly trained personnel and complete facilities are necessary.

FAILURE RATE AS A FUNCTION OF TIME

The idealized curve of component failure rate versus time is shown in Figure 1. Several features of this familiar "bathtub" curve are important in any consideration of diode reliability. The first portion of this curve indicates a sharply increasing and then a steadily decreasing failure rate during the "burn-in portion" of rectifier life. The increasing failure rate for the very early life portion of Figure 1 may not always be seen. The portion of this curve which shows a decreasing failure rate for rectifiers has been demonstrated. These early life failures are generally classified as a result of poor workmanship.

The failure rate during the very early life depends upon a number of factors. Among these are the actual zero time in the life of the component,

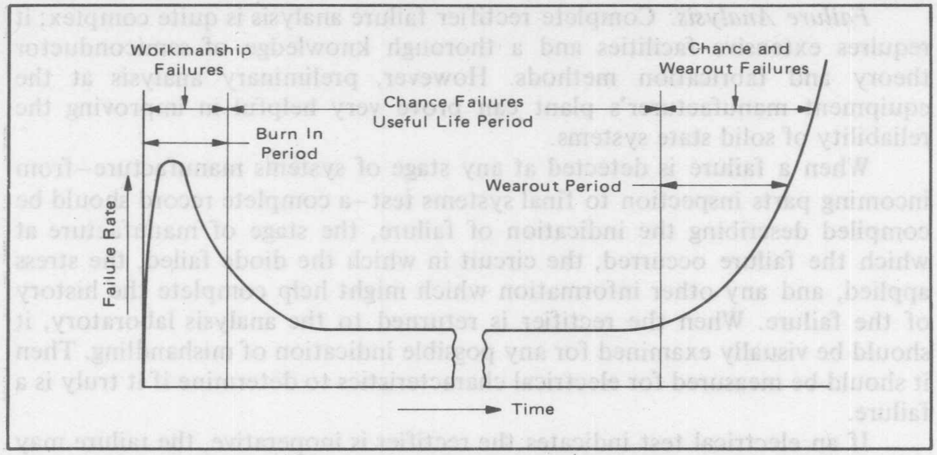


Figure 1 — Failure Rate as a Function of Time

the definition of failure, and of course, the inherent reliability of the product. Actually, the life of a rectifier begins when the encapsulating process is completed. On Motorola's high-reliability lines, a period of stressing at elevated temperature is standard operating procedure in order to stabilize characteristics. The time and the stress applied during this stabilization process will affect the early-life failure rate, and, thus, they will significantly affect the shape of the very early portion of the failure rate versus life-curve.

The criteria used to define a failure will affect the failure rate for any given period of time. For example, a rectifier type, which has a certain amount of instability of characteristics early in life, can exhibit different failure rates depending upon the relationship of test limits initially and limits after a specified period of time. When tested to a life-test specification which defines a failure as exceeding the initial electrical parameter limits, these rectifiers will have a higher early-life failure rate than they would have had if tested to a specification with life-test limits relaxed from initial limits. If parameters continue to drift with time, even the relaxed life-test limits would be exceeded and the total number of failures would be the same, regardless of the specified limits. However, if the rectifier should stabilize after a short period of time, as is often the case, then the failure rate would be less to the relaxed life-test points.

The idealized failure rate versus time curve shows that after the initial high and decreasing failure rate period, which can be attributed to workmanship faults not detected during the manufacturing process, a period commences of relatively constant failure rate at a low level. This is the period of random failures.

The final portion of Figure 1 shows an increasing failure rate indicated as "wear-out". This portion is extremely difficult to define and will vary depending on the method of fabrication and applied stress. This increasing failure rate can be introduced by such mechanisms as thermal fatigue of the solders between the silicon die and the mount (due to repeated cycling of junction temperature while the case is at more or less a fixed temperature), by glass hermetic seal failures (due to environmental cycling), by fatigue of internal construction (due to mechanical stress), or by bulk defects. Little

data is available from either life-tests or system field-tests to permit an accurate picture of this portion of the curve. Contrary to the early life failures which may be characterized as workmanship faults, the failures which occur in the wear-out period are believed to be a result of basic design limitations.

The fact that failure rate is not constant with time throughout rectifier life dictates that any statement of failure rate must refer to the time period considered. In this chapter all failure-rates are based upon the first 1000 hours of life tests unless otherwise stated. This changing failure-rate during life is a reason for not using MTBF as measure of reliability on an individual rectifier basis.

SCREENING PROCEDURES

Since many early life failures are the result of manufacturing flaws, it is quite possible to develop screening procedures to improve reliability. Actually most reputable manufacturers employ screening procedures as a regular part of the fabrication process. The effectiveness of any screen procedure must be carefully verified for the particular semiconductor under consideration.

All rectifiers are measured for significant electrical characteristics to detect devices with abnormalities which may cause poor reliability. Most bulk and surface defects are detected at electrical characteristics screening. Depending on the manufacturing process used, screening tests such as power-applied burn-in, temperature cycling, and high temperature storage may be employed. Unless screening processes are properly selected, however, they may have the opposite effect of actually reducing rectifier life. For example, extreme mechanical stresses may not only destroy weak units, but may weaken good units.

MEASUREMENT OF RELIABILITY

The ultimate measure of rectifier reliability is performance in intended applications. However, since long-term tests at use-conditions are not feasible from either time or cost considerations, more practical test procedures have been developed to assure reliability.

The intent of these tests is to accelerate testing by increasing the failure rate so that a measure of long-term reliability may be obtained in a relatively short time (1000 hours) and to accelerate stresses so that a relatively small number of components may be tested at high stress levels to assure very low failure rates under normal use conditions.

Matrix Testing: A matrix program includes the testing of a number of devices under a range of test conditions designed to stress the potential device failure mechanisms. Aside from mechanical and environmental stresses, a semiconductor device will be stressed during use by voltage, current, ambient temperature, and junction temperature. These conditions are not independent. In fact, they are closely interrelated.

To determine the extent of the effect of these stresses on semiconductor device reliability, an experiment is designed to test devices under various combinations of these stresses. Statistical analysis of these tests results at specific stress points, permits the prediction of failure rates at

other stress conditions, and provides a relative measure of the effects of various stress conditions, i.e., develops acceleration factors.

Extensive matrix testing programs cannot often be economically justified. However, even in a much simpler form these approaches can provide significant results in determining a relationship between failure rates under high stress conditions and those at use-conditions.

A vital precaution which must be observed in matrix testing or any other accelerated test plan is to assure that no new failure mechanisms are introduced by the accelerated stress which will not be encountered in normal circuit use. If the high stress tests introduce new failure mechanisms, then they lose validity in predicting long-term life.

Step-Stress Testing: The step-stress test method has the advantage over matrix testing in that it is a relatively short-time test. Step-stress testing consists of subjecting the devices being evaluated to successively increasing levels of stress until a majority of the devices have failed. Step-stressing can be done for mechanical stresses such as constant acceleration, electrical stresses such as surge current or power dissipation, and ambient stress such as temperature.

Though a number of applications have been proposed for step-stress analysis, the most useful application is providing relatively fast comparative analysis. Step-stress analysis can be used to determine:

(1) The comparative effect of manufacturing process changes on reliability.

(2) The variation in reliability of lots manufactured at different times.

(3) Comparative analysis of similar types supplied by different manufacturers.

SPECIFYING RELIABILITY ASSURANCE

The factors which influence the degree of reliability assurance obtained by testing a sample of rectifiers are:

(1) The stress applied.

(2) The sampling plan used.

(3) The criteria of failure.

(4) The number of failures permitted.

All of these factors must be specified if adequate reliability verification is to be assured:

Stress: The stresses applied should be chosen to accelerate failure mechanisms which can cause failures during system life. Acceptance testing is almost universally conducted under maximum rated conditions. Since the stresses the rectifier encounters during life in well designed systems are less than the maximum rated, the acceptance life test is an accelerated test.

Sample Plan: In any plan by which the quality of a large population of devices is assured by testing a sample of that population, there is an element of risk that the measured quality of the sample will not give an accurate picture of the quality of the total population. The smaller the absolute size of the sample and the smaller the sample is in relation to the total

population, the greater the risk that the measured quality of the sample is not the true quality of the total population. The sample test results may give an accurate, a pessimistic, or an optimistic picture of the true quality of the total population. The sample plan must be selected to give as accurate a picture of the total population as cost and time limitations permit.

The accuracy with which the sample test results measure the quality of the total population is known as the confidence level. If it is desired to use the results of a sample test to state a reliability level for an entire lot, then the maximum failure rate decreases as the confidence level increases. Thus, any statement of failure rate must include information as to whether it is a measured failure rate or whether it is a maximum failure rate. If it is a maximum failure rate, then the associated confidence level must also be stated.

Two basic methods of sampling quality assurance are in use in the semiconductor industry today. These are the AQL and the LTPD plans. The AQL (Acceptable Quality Level) procedure has been in use for a number of years. Under it, an inspection level and an AQL are specified. For each lot size, the inspection level specified determines the number of samples required. The number of samples to be tested increases as the lot size increases, but the ratio of sample size to lot size decreases for larger lots. MIL-STD-105 "Sampling Procedures and Tables for Inspection by Attributes" specifies the sample size for any inspection level and lot size, and stipulates the number of failures permitted for any AQL. The AQL value is approximately the maximum average percent defective permitted if 19 out of 20 lot submissions are to be accepted.

The AQL system is known as a "producer risk" plan because the producer's risk is specified while the risk the user is taking is not specified. The manufacturer has an approximately 5% chance of having a lot rejected if the percent of defective devices is more than the specified AQL. The lots accepted, however, could have considerably higher percent defectives than the AQL indicates. This method of quality assurance is especially unsatisfactory if the sample size is small.

The LTPD (Lot Tolerance Percent Defective) method of quality assurance has gained increased acceptance in recent years. Under this procedure, assurance is given that only infrequently (generally 10% of the time) lots with a poorer quality than that specified will be passed. Since under this plan the user is protected against receiving poor quality 90% of the time in comparison to the AQL system which protects the manufacturer from rejecting good quality product 95% of the time, the LTPD system is a "user risk" plan because the risk of the user is specified.

The LTPD levels which are typical for current military specifications are an LTPD of 5 with a minimum rejection number of 5 for mechanical and environmental tests, and an LTPD per 1000 hours* of 10 for life test. No minimum rejection number is usually given for life test because test cost will limit the size of the samples which can be life-tested for 1000 hours. The cost of testing may be a definite limitation upon the level of reliability assurance which may be verified by acceptance testing. This is especially true when acceptance tests are performed by sampling lots of rectifiers which have been accumulated in response to specific customer orders. The degree of reliability assurance which can by this method be economically provided for specific orders is probably limited to an LTPD of 10%.

*LTPD per thousand hours is designated λ.

The relationship between AQL and LTPD is illustrated by Figure 2. This curve is the operating characteristic for an AQL of 4.0% at sample sizes 15 and 150. An operating characteristic may be said to be a measure of ability of an acceptance plan to distinguish between acceptable and reject lots. The ideal operating characteristic is a vertical line intersecting the abscissa at the desired quality level. (This ideal operating characteristic can only be achieved by 100 percent inspection. At less than 100% inspection, the operating characteristic is a measure of the degree with which the results of the sample test assure the quality of the total lot.) For smaller sample sizes, the effectiveness of the AQL procedure in assuring quality becomes poor. In Figure 2 for a 4.0% AQL, a sample size of 150 will permit 1 lot out of 10 with an 11 percent defective to pass, while a sample size of 15 will permit a lot with 25% defectives to pass 10% of the time. Under the LTPD procedure the sampling plan is such that the lower end of the operating characteristic is controlled so that no more than 1 in 10 lots can pass if the specified LTPD is exceeded.

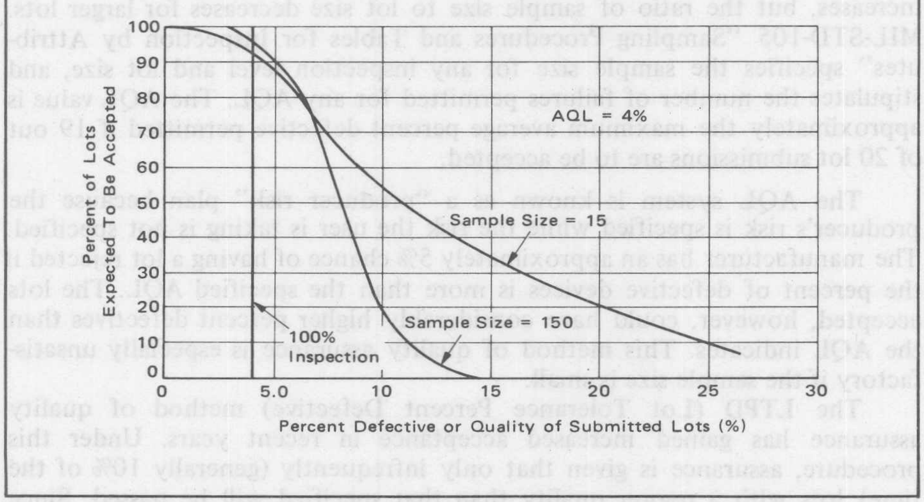


Figure 2 — Operating Characteristics for a 4% AQL

Under the LTPD plan, sample size is independent of lot size. MIL-S-19500 lists sample sizes and the number of rejects permitted for various LTPD's. The percent defective, permitted in a sample size required to assure a specified LTPD, increases as the sample size increases. Under a pure LTPD plan, the percent defective permitted in the sample approaches the actual specified LTPD as the sample size approaches 100% inspection.

The LTPD's included in typical military specifications are generally larger than the AQL's formerly specified. Thus, for large-sample sizes greater quality assurance protection might be obtained from a typical AQL military specification than from an LTPD specification. Since the purpose of the military specification groups in adopting the LTPD system was not to reduce the known quality of components accepted, but to reduce the risk of material of poor quality being unknowingly passed due to sampling risk, a

modified LTPD plan is in general use today. Under this modified LTPD plan a maximum acceptance number or minimum rejection number is specified. (Minimum rejection number equals maximum acceptance number plus one.) Under this procedure the quality may be verified by selecting a sample not larger than a specified size. The lot may be accepted by testing smaller sample sizes, but the permitted percent defective of the sample is less.

This modified LTPD plan gives added consumer protection against the possibility of receiving poor quality because of the risks involved with small lot and sample sizes, which might occur under the AQL system. Yet this plan limits the minimum quality which can be shipped to that which would be assured by an equivalent AQL for large lot sizes.

Criteria of failure: The criteria of failure (end points) is the third factor in specifying reliability assurance. Three methods of specifying failure are in common usage today. These are:

(1) The end point limits are the same as the initial electrical limits.

(2) The end point limits are relaxed from the initial limits.

(3) The maximum shift of parameter characteristics are specified on an individual basis.

The second method has been the most widely used. The first method is often used for "high reliability" specifications, but its value is somewhat questionable. This method of specifying end-of-life limits does not take into account any possible inaccuracy in repeating parameter measurements during a test of several weeks. If minor shifts in rectifier characteristics are causing problems in meeting the end point limits, the manufacturer can institute a parameter screen to select rectifiers to tighter than the specified initial limits. Thus, in effect, no greater parameter stability than given by method two is assured. Specifications which have identical initial and end-of-life limits may dictate that the quality assurance provisions, (i.e., AQL or LTPD), be quite loose in order to avoid lot rejection due to relatively minor parameter shifts or inability to precisely repeat measurements.

The third method, which is to specify permitted parameter shift on an individual basis, has considerable merit for assuring the delivery of stable rectifiers. This method is the most expensive of the three to implement, because it requires that data on each characteristic be recorded and that calculations be performed on the shift of each characteristic for each rectifier to determine if the lot meets the specified quality assurance provisions. A precaution which must be observed when this method is used, is to be sure that measurement accuracy is much greater than the parameter shift permitted. A specification using parameter shift as a criteria should specify a percent shift or an absolute value, whichever is greater. For example, for a rectifier with an initial limit for I_R of 1 microamp, the end of life limit in relation to the initial values could be specified as +50% or +0.5 microamps, whichever is greater.

In the specification of end points, a careful compromise must be reached between making the end points tight enough so that poor reliability will be detected, and yet not so tight that any minor shift in characteristics will reject the lot. Probably the best compromise is the use of double end

points. This would consist of a relatively tight limit, perhaps a maximum shift of parameters, to a relatively loose LTPD, and looser limits to a tighter LTPD. For lot acceptance both criteria must be met. It should be noted that with this method the sample size which must be tested is dependent upon the tighter LTPD (or AQL), so this will govern the test cost.

Failures Permitted: In addition to the elements of stress applied, sampling used, and criteria of failure, the number of failures permitted remains to be considered in order to adequately specify acceptance procedure for reliable rectifiers. The number of rejects permitted, of course, depends upon the quality assurance required. The use of a reliability assurance plan which permits no rejects should be avoided because the possibility of a random failure exists even in the most reliable product and the most carefully conducted tests.

ACHIEVING RELIABLE SYSTEM PERFORMANCE

Reliable system design must consider two basic requirements, the selection of reliable components and the proper circuit design. Factors to consider in choosing components and a checklist for circuit design are presented in the following sections.

Selecting Rectifiers: The foundation upon which any reliable equipment design must be based is reliable components. Without reliable components even the most careful design cannot result in maximum equipment reliability. Of course, the prime consideration in the choice of rectifier type is its capability to perform the electronic function required. Generally, at the circuit design stage, any one of a number of types could be selected to give satisfactory performance. However, the reliability of these types may not be equal. A number of factors must be considered in the choice of a rectifier type when reliability is of prime importance: There are:

(1) Has the reliability of the device under consideration been proven? New rectifier types with better electrical characteristics are constantly being announced. There is too often a tendency on the part of circuit designers to select these devices because of their high performance capabilities. It must be noted that it takes time to adequately prove the reliability of a rectifier and that, generally, the reliability of newer types has not been verified to the extent of older types.

(2) Has the rectifier been in production long enough for any problems, which may adversely affect reliability, to have been eliminated? Early in the production phase of a rectifier type, major emphasis is often given to process improvement to improve electrical characteristics. As the production process and yields improve, reliability will generally also improve.

(3) Is the rectifier type under consideration a major portion of the manufacturer's yield? A characteristic of the semiconductor industry has been that a number of types of varying electrical characteristics are simultaneously produced on the same line. As manufacturing experience is gained, the process can be adjusted to

increase production of the most desired types. However, it is often true that a type which represents a small percentage of the yield of a production line may have some abnormality which will make its reliability different from the majority of the line output.

(4) Does the rectifier manufacturer have a good reputation for integrity and competence? This criterion is probably the most significant of all listed. It is really the basis for the 3 listed above. A well-known manufacturer with a good reputation for reliability has demonstrated his interest in producing a good product and fairly representing it. This type of manufacturer will take the time necessary to assure reliability.

Circuit Design Considerations

The selection of the most reliable rectifier to perform the required function is basic, but it is only the first step in assuring the reliable circuit operation. Several circuit design considerations to assure reliable performance follow:

(1) When possible, circuit performance should be based upon the most stable parameters.

(2) Realistic limits for component variations due to tolerance, temperature, and time should be used. Wider limits must be allowed for characteristics which are less stable, such as I_R, than those which show good stability with life.

(3) Circuit design which is dependent upon rectifier characteristics that are uncontrolled can lead to poor reliability and should be avoided. If circuit performance is dependent upon rectifier characteristics which are not specified, and thus not controlled, there is no assurance that subsequent production will have the same characteristics.

(4) The environment which the rectifier, circuit, and system encounters during assembly, testing, and use, must be controlled to assure maximum reliability.

(5) The use of derated operating conditions can be a factor to secure reliable circuit performance. The conditions to be derated and the amount of derating must be carefully determined to insure reliable circuit operation and still maintain required performance. Circuit performance and reliability, in this sense, compromise each other.

Derating: The relationship of derating and reliability has been introduced in previous sections, but it warrants added emphasis. The manufacturer must conduct his reliability tests under accelerated conditions at or above maximum device ratings because of time and cost limitations. Furthermore it is necessary to obtain data quickly which can be fed-back into the manufacturing line to enable corrective action to be taken if necessary.

The amount of rectifier derating which should be employed for any application depends upon a number of factors:

(1) The system reliability requirements.

(2) System design constraints such as size, weight, power supply, capacity, etc.

(3) The crossover point between the rectifier reliability gained by derating and the loss of reliability by added circuit complexity.

(4) The point of diminishing returns where added derating will not ıcrease rectifier reliability significantly.

(5) The cost of components having specifications better than that dictated solely by electrical requirements.

Of course these questions can only be answered for a particular equipment design and for a particular type. However, some general rules can be stated as guides:

(1) Junction temperature is probably the most significant factor affecting semiconductor reliability. Limiting the maximum junction temperature rise to approximately 50% of maximum ratings is probably the most effective method of improving reliability. A fact which must be remembered in any consideration of temperature derating is the method of verifying rectifier dissipation ratings. Some types are life-tested under rated dissipation at room temperature and by a non-operating life-test at or above rated junction temperature. This method of life-testing is valid to guarantee the derating curve only if the room temperature operating test brings the junction to maximum operating temperature. If rated junction temperature is not reached during the operating life-test, a higher failure rate may be encountered than anticipated, if the rectifier is operated at an ambient temperature higher than 25°C.

(2) Since unpredicable voltage transients account for a significant percentage of field failures, derating voltage by 50% is a good practice.

(3) The maximum feasible derating of mechanical stresses is desirable for maximum reliability.

PRECAUTIONS FOR THE EQUIPMENT MANUFACTURER

To insure maximum rectifier reliability from incoming inspection through outgoing system final test, a number of precautions should be observed. Among these are:

Handling Precautions:

(1) Rectifiers should be handled in a manner which avoids the possibility of sudden shocks being applied, such as those encountered in dropping from a work bench to a hard floor. Damage done to the rectifier by such shocks may not be detected by subsequent testing, yet may cause poor system reliability.

(2) Any lead trimming or other handling operation should be done with care to avoid damaging the leads or the glass header seals.

Hand trimming of leads with pliers should be avoided unless care is taken to avoid pulling the leads.

(3) Care must be taken during all soldering operations. Hand soldering should be avoided if possible. If hand soldering is done, a heat sink such as a pair of pliers should be clamped on the lead between the point of application of the soldering iron or gun and the rectifier. Dip soldering should be limited to the minimum time and temperature required to make reliable connections. It is unsafe to exceed the general specification to which diodes are tested for solderability. This is 10±2 seconds at a temperature of 230°C ± 5°C at a point 1/16 ± 1/32 inch from the diode body.

Precautions should be taken to prevent solder or flux bridging which causes a conductive path across the case of the rectifiers.

(4) Ultra-sonic cleaning of printed circuit boards should be carefully controlled. The energy level used should be the minimum possible. The presence of standing waves in the bath should be avoided, perhaps by the use of a source with slightly varying frequency. The board should be held as firmly as possible to minimize ultrasonic vibration. The particular method of ultrasonic cleaning to be used should be thoroughly evaluated to assure that it does not cause damage.

Testing Precautions:

(1) Voltage and current surges must be avoided at any system test station. The rectifier leads should be grounded during any test system switching. The transmission of surge voltage through common power lines to test systems has caused failures.

(2) For all leakage tests, a suitable resistor should be placed in series with the rectifier under test and the supply, to limit the current in case of high leakage or a short. If this is not done, complete destruction of the rectifier could occur which will prevent further analysis of the failure. Care should be exercised to insure that thermal runaway will not occur if dc leakage is being measured at high temperatures.

CHAPTER 13: RECTIFIER SELECTION CONSIDERATIONS–SERIES AND PARALLEL CONNECTIONS

The three major parameter extremes encountered in rectifier applications are voltage, current, and speed. In each case, there is more than one way to achieve the desired performance, but some of these approaches represent a compromise of other characteristics. The user must be aware of these trade-offs if the best cost/performance ratio is to be obtained.

HIGH VOLTAGE APPLICATIONS

There are several techniques that can be used to obtain rectified voltages in the 10 kilovolts and higher range. For purposes of discussing rectifier requirements the approaches may be grouped into *direct rectification* and *multiplying rectification.*

The direct method uses an ac voltage source sufficient to provide the required dc voltage. The rectifier could be half-wave, full-wave, or a full-wave bridge assembly. In contrast, the multiplier approach uses an ac voltage source that supplies only a fraction of the final voltage needed into a special rectifier-capacitor network to achieve the final voltage. A more complete discussion of multiplier circuits can be found in Chapter 7.

The simpler direct approach places a more severe burden on the diode in high voltage schemes since there is a practical voltage limit that a single silicon diode can handle. This limit, about 2kV, represents the state-of-the-art in single-cell units. Although higher voltage diodes are possible, they suffer from a higher voltage drop and a lower frequency response; the necessarily large depletion region in a high voltage device requires a physically wide high resistivity region.

The obvious solution to this dilemma is to series-connect several diodes into a "stack" to get the needed voltage capability. Unfortunately when diodes are connected in this manner, operating failures occur unless the diodes are closely matched or compensated. Reasons for the failure can be explained by examining Figure 1. When reverse leakages are not matched (represented by R in the simplified model), then the reverse voltage impressed on the string is divided unevenly across the units and usually

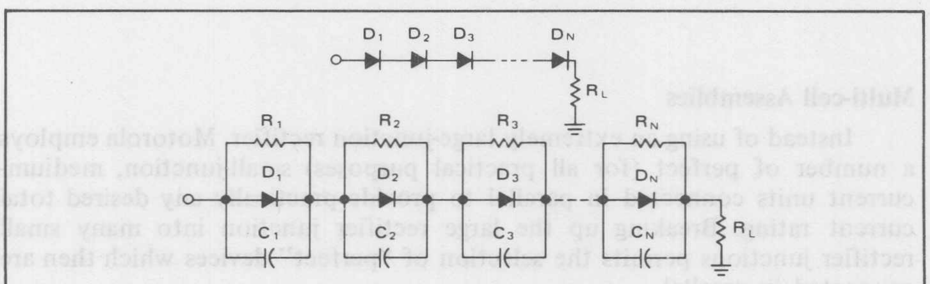


Figure 1 – A diode string with a simplified model showing reverse leakage (R), and distributed capacitance (C).

places operation in the breakdown region for the unit with highest resistance. If one unit fails, it places an increased voltage across the others resulting in another failure, and so on. A fast rising input pulse (transient, turn-on spike, or wavefront when phase control with SCRs or triacs on the input ac is used) can also be unequally shared if the diode RC time constants are not equal.

In the past, series units were compensated by the addition of a parallel resistor and a capacitor to each cell that would dominate the diode characteristics. In addition to degrading the rectifier circuit characteristics, the network adds bulk and cost. The only alternative is to carefully match each cell going into a series string. This too can be expensive for the user since it involves considerable testing; for successful implementation, five basic parameters must be matched: turn-on time, reverse-recovery time, reverse breakdown, capacitance, and reverse leakage. This overwhelming task can be done by the manufacturer relatively easily and with a considerable cost advantage as will be seen.

HIGH CURRENT APPLICATIONS

Several techniques are in use to provide rectifier systems with current outputs in excess of the capability of a single die. Die capability is limited because as current requirements are increased, junctions must become larger and larger. Large-area rectifier junctions cannot be made without some imperfections and the larger the area, the greater the number of imperfections. When current is passed through such a device, the current is not necessarily distributed equally over the entire area. Some areas will assume more than their normal share of current, and these high-current areas may ultimately result in high heat density areas ("hot spots") which can cause thermal fatigue and deterioration. During abnormally high current surges, such thermally stressed or deteriorated areas can assume excessive current and destroy the entire rectifier.

At currents where a single rectifier die becomes either too unreliable or costly, some means of parallel connection and current balancing among units must be employed. The user has two options:

(1) a factory matched and assembled unit may be purchased, e.g., a "multi-cell" assembly;

(2) standard or matched units may be purchased and assembled under the direction of the user.

Factors to consider when pursuing either option are discussed in the following sections.

Multi-cell Assemblies

Instead of using an extremely large-junction rectifier, Motorola employs a number of perfect (for all practical purposes) small-junction, medium-current units connected in parallel to provide practically any desired total current rating. Breaking up the large rectifier junction into many small rectifier junctions permits the selection of "perfect" devices which then are connected in parallel.

To overcome the basic problem inherent in the use of multiple paralleled rectifier cells, i.e., achieving equal current distribution, Motorola matches and guarantees the forward-voltage characteristics of each cell to within 20 millivolts at 100 amperes. These closely matched rectifier cells are then mounted on a common copper base in a manner which intimately couples each cell thermally. Under normal operating conditions, the thermal difference between cells is so low that any current unbalance is negligible.

Other advantages of the parallel-cell concept areas are as follows:

(1) the entire rectifier assembly can be factory tested prior to final assembly and any substandard cells can be replaced;

(2) a number of reserve cells can be "built in" to provide an extra current margin;

(3) current-handling potential is virtually unlimited (a 2,000-ampere unit has performed satisfactorily);

(4) higher current devices mean a sharp reduction in the number of expensive "accessories" (balancing transformers, paralleling reactors, etc.) previously required on many applications;

(5) the user can bolt the unit to busing without a torque wrench. There is virtually no possibility of damaging the individual cells by overtightening either the stud bolt or the lead connection, because there is no fragile insulator-to-metal hermetic seal between external leads and case (an inherent characteristic of single-junction devices).

Parallel Connections

Certain applications may still arise which require considerably greater currents than can be drawn from circuits with one rectifier per leg. When rectifiers must be paralleled, the current loads through each rectifier must be balanced.

In order to attain the proper division of current when paralleling silicon diodes, the following procedures are in current use:

(1) factory matched forward characteristics.

(2) the addition of resistance or reactance in series with each diode.

(3) balancing transformers or separate transformer windings.

Factory matched diodes are selected so that they will divide current properly during the normal steady-state conduction and the overload or fault conditions. Depending on the manufacturer's recommendation, the average current rating per diode must be lowered in order to compensate for the known unbalance that will remain. Use of a common heat sink is mandatory in order to keep the junction temperature nearly the same and thus assure voltage tracking with current and ambient caused temperature changes.

Generally no more than six to ten diodes should be paralleled unless careful consideration is given to the bus reactance and resistance design. Resistors used in series are the simplest method of forcing current division and are generally chosen so that the combination has a peak voltage drop approximately 30% higher than the diodes alone at the normal load current. (Fuses, in series with each rectifier, may supply all the resistance required.) In this manner, current division is markedly improved but unfortunately, more power loss is introduced into the equipment. The use of individual reactors in series with each diode offers a better choice from the standpoint of efficiency.

Use of balancing transformers is a very effective means of forcing proper current balance and may be less expensive than purchasing factory matched units. The transformers consist of laminated iron cores usually with single-turn primary and secondary windings. The current from two diodes in parallel passes around the core in opposite directions so that any unbalance will induce a voltage which serves to correct the unbalance. The basic technique is shown in Figure 2. Its extension to larger numbers of rectifiers is illustrated and briefly discussed in Figure 3.

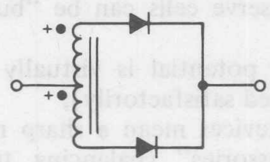
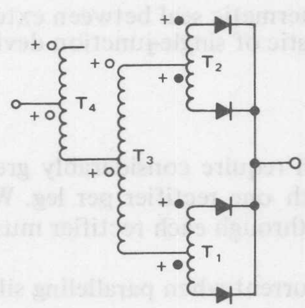
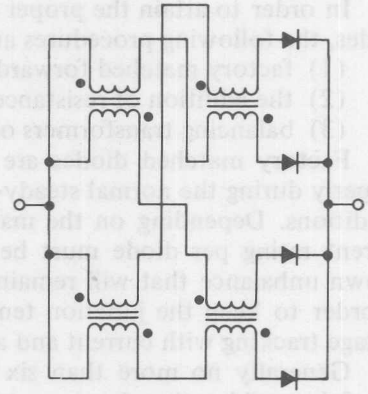


Figure 2 – Parallel Operation of Silicon Rectifiers Using Balancing Transformers



(a) Balancing Reactors Used with Diodes in an extension of the basic circuit. Transformer T_3 must handle twice the current of T_1 or T_2; T_4 must handle twice the current of T_3, etc.



(b) Balancing Reactors in a Closed-Chain System. Each winding carries only the current of one diode.

Figure 3 – Schemes for balancing the current when more than two diodes are required.

CHAPTER 14: HIGH FREQUENCY APPLICATIONS CONSIDERATION

The term *fast recovery* has become synonymous with *high speed* or *high frequency* diodes since the longest time delay in switching a p-n junction is the reverse recovery time. This delay is the time it takes for charge carriers to recombine across the junction. During this period there is also a momentary but high reverse current flow. In a filtered supply this recovery "spike" is absorbed by the filter capacitor, but the power loss in the rectifier may be significant at high frequencies.

The recovery time of a rectifier can be shortened by providing more recombination sites for the charge carriers. Some manufacturers use radiation techniques to generate crystal dislocations that serve as recombination centers. While this technique has proved successful for small signal units, it leads to poor reliability and a short life in power devices. Gold doping has been found to be a very effective method for establishing additional recombination centers and, though it raises the band gap of the material (slightly increasing forward voltage drop and reverse leakage), it provides the best reliability-lifetime characteristics.

The Schottky Barrier or Hot Carrier diode operates on a different principle than a conventional p-n junction. No minority carrier flow occurs: hence there is no charge storage and no reverse recovery time. No real reverse power loss results, even though a reverse transient current occurs; the current is simply a displacement current drawn by the barrier capacitance. Rectification efficiency measurements indicate that operation is satisfactory up to the megahertz region.

The use of a barrier metal, as in the Schottky diode, reduces the band gap well below that of conventional p-n junctions. The resulting low forward drop is another feature of the Schottky device, but it is also accompanied by an increase in reverse current according to the law of the junction. (See Chapter I). Because reverse current is high and increases with temperature, proper attention must be devoted to the thermal design to avoid thermal runaway as discussed in Chapter 2. However, the reverse power loss is more than compensated for by the low forward power loss.

COMPARISONS OF SCHOTTKY RECTIFIERS MADE WITH DIFFERENT BARRIER METALS*

Summary

Comparisons are made between Schottky Rectifiers made with different barrier metals. Forward voltage and reverse current are examined at high temperatures and power losses computed. It is found that Platinum barrier devices offer lowest overall power losses due primarily to their low forward voltage at high current levels combined with relatively low reverse current. Chrome barriers produce the lowest voltage drop at low current levels but have the highest reverse leakage current. Molybdenum and Tungsten barriers occupy intermediate positions.

Schottky rectifier diodes were purchased from various manufacturers to obtain a sufficient sample size of diodes having different barrier metals. In order of increasing barrier height, the metals are of chromium, molybdenum (moly), tungsten and platinum. Forward and reverse data were obtained over a wide range of operating conditions. From this data, typical forward and reverse characteristics were found for each barrier metal. However, since the commercial products available vary in die size, it is necessary to normalize the data because the forward voltage drop is a function of current density and reverse current is proportional to die area. Thus normalized, the data reflects the inherent differences due primarily to barrier metals (similar EPI's assumed).

Figure 1 shows the results of the tests when normalized to a die area of 160 x 160 mils at a temperature of 125°C. At low currents, the forward voltage reflects the barrier height. Chrome is lowest at currents below 55 amperes, while platinum is lowest at currents above 50 amperes. Furthermore, platinum exhibits a drop lower than the next best material, moly, down to a current of 11 amperes. Therefore, this data indicates that different barrier metals will provide lower forward losses in different current ranges.

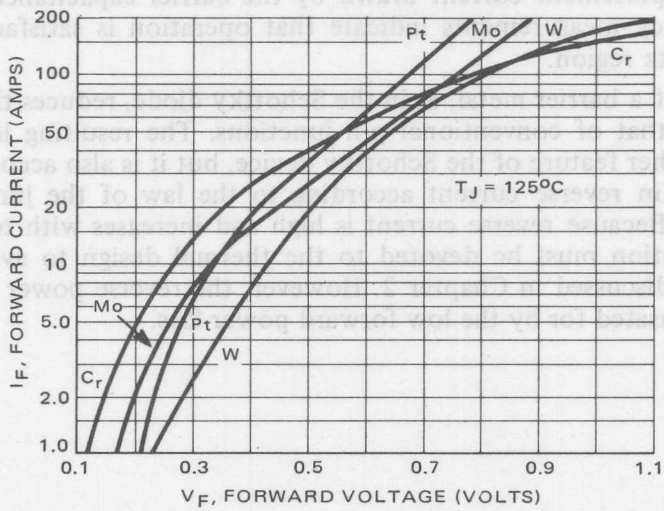


FIGURE 1 – Forward Characteristics

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*Bill Roehr and Jerry Walton; printed in Electronic Design, March 1, 1979. Printed in SOLID-STATE POWERCONVERSiON, January/February, 1979.

The reverse leakage as shown in Figure 2 also shows the expected relationship to barrier height. Chromium is quite high and tungsten is the lowest; the platinum diodes are a close second behind the tungsten, particularly at higher voltages.

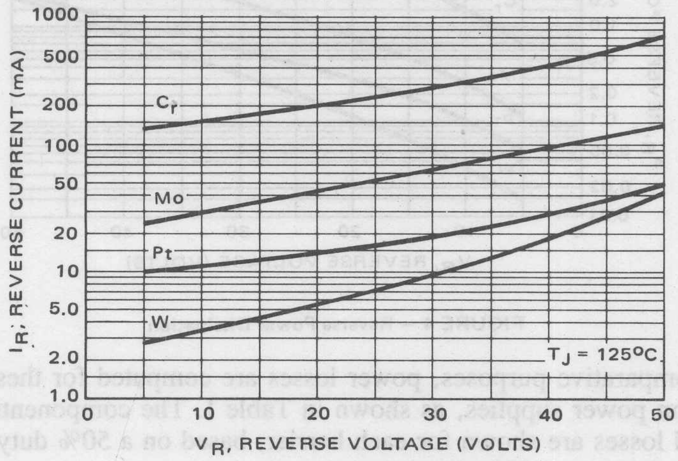


FIGURE 2 – Reverse Characteristics

The significance of the data is evident when it is translated into power losses. Figure 3 is a plot of the peak forward power loss of the various rectifier diodes; the reverse power losses are shown in Figure 4. Rectifier diodes of this die area would normally be housed in a DO-5 package having a thermal resistance limit of 1°C/W and would be rated to handle approximately 50 amperes average of square wave current (100 A peak) so that a pair of diodes would produce an output of 100 Adc in a full wave circuit.

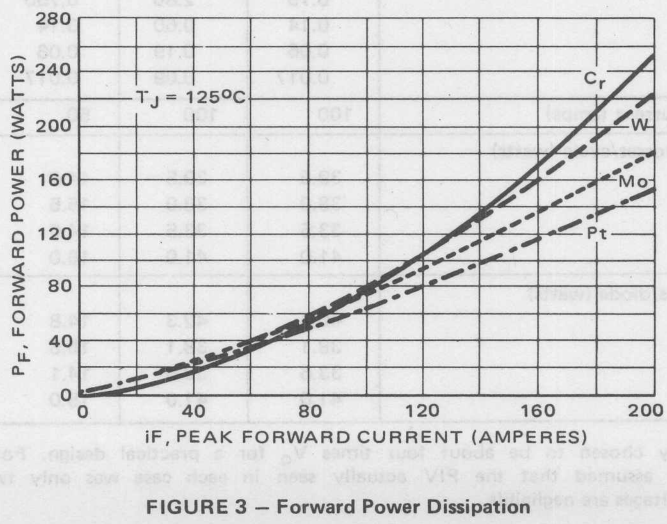


FIGURE 3 – Forward Power Dissipation

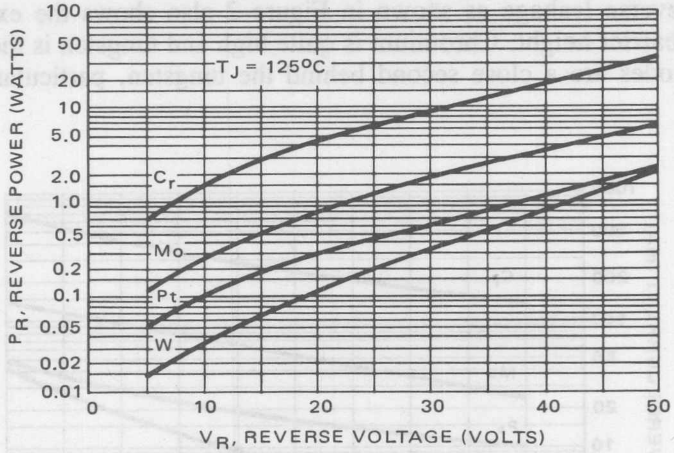


FIGURE 4 – Reverse Power Dissipation

For comparative purposes, power losses are computed for these diodes in four common power supplies, as shown in Table I. The components of reverse and forward losses are shown for each barrier, based on a 50% duty cycle, that is, equal conducting and blocking times.

It is evident that the platinum devices offer the lowest losses under all conditions. The chrome barrier is quite close in the 50 A, 5.0 V supply and moly ranks second in the 100 A applications.

TABLE I

TYPICAL LOSSES IN COMMON FULL WAVE 20 kHz RECTIFIER APPLICATIONS

DC OUTPUT CURRENT, I_o DC OUTPUT VOLTAGE, V_o	100 A 5.0 V	100 A 12 V	50 A 5.0 V	50 A 12 V
Rectifier PIV* (volts)	10	24	10	24
Diode reverse losses/cycle (watts)				
C_r	0.75	2.80	0.750	2.80
Mo	0.14	0.60	0.14	0.60
Pt	0.06	0.19	0.06	0.19
W	0.017	0.09	0.017	0.09
Peak rectifier current (amps)	100	100	50	50
Diode forward losses/cycle (watts)				
C_r	39.5	39.5	14.0	14.0
Mo	38.0	38.0	15.5	15.5
Pt	33.5	33.5	14.0	14.0
W	41.0	41.0	16.0	16.0
Total power loss/diode (watts)				
C_r	40.3	42.3	14.8	16.8
Mo	38.1	38.1	15.6	16.1
Pt	33.6	33.6	14.1	14.2
W	41.0	41.0	16.0	16.1

*PIV is typically chosen to be about four times V_O for a practical design. For these calculations, it was assumed that the PIV actually seen in each case was only two times V_O; i.e., transient voltages are negligible.

Transient effects have been neglected in this study as tests have not detected any significant effects in Schottky rectifier diodes when used in high power conversion equipment. Transient effects may exist, but the rate of rise achievable at high current levels is insufficient to reveal any significant diode forward or reverse recovery time. Overshoot voltages during turn-on have been observed, but these are due to the package lead inductance and do not contribute to power losses.

The difference in power losses between the various barriers may not seem particularly significant when compared to the overall power level of the supply. That is, who cares whether a few watts can be saved in the 100 A, 5.0 V supply since 500 watts are being handled. However, the power saving shows up significantly in the heat sink requirements as illustrated in Table II. Note that the chrome and tungsten parts require about 50% more heat sinking than platinum. The Table is based upon $T_J(MAX) = 125°C$.

TABLE II

TOTAL RECTIFIER HEAT SINK REQUIREMENTS FOR 100 A, 12 V SUPPLY AT $T_A = 55°C$, $T_{J(AV)} = 125°C$, $R_{\theta JC} = 1°C/W$

Barrier	Rectifier Circuit Power Loss (watts)	Maximum Allowable Case Temp. (°C)	Minimum Heat Sink Thermal Resistance (°C/W)
C_r	84.6	82.7	0.32
W	82.0	84.0	0.35
Mo	76.2	86.9	0.42
Pt	67.2	91.4	0.54

TRANSIENT RESPONSE MEASUREMENTS OF HIGH SPEED RECTIFIER DIODES*

Selecting a rectifier diode for use in high frequency converter circuits involves a number of trade-offs and a number of circuit constraints must be considered. Many of these have been discussed by Fred Blatt.[1] In summary, the characteristics to be balanced include primarily forward voltage (V_{FM}), reverse voltage (V_{RWM}), and reverse recovery time (t_{rr}). The Schottky barrier diode is generally regarded as the best choice for low voltage supplies (12 volts or less) because of its extremely low forward voltage drop, which, coupled with its freedom from stored charge effects, yield a low loss rectifier circuit. However presently available V_{RWM} is limited to 50 V. Recently, p-n junction devices often made by a combination of ion-implantation and epitaxial technology have been introduced which offer high speed and voltage ratings to 150 V, with forward drops somewhat lower than the ordinary fast recovery rectifier diodes. These diodes appear to warrant first consideration in supplies in the 10 to 24 volt range, particularly if voltage transients are a problem. The ordinary fast recovery device is often satisfactory in higher voltage supplies. Switching speed of any of these diodes is satisfactory from a rectifier efficiency point of view if operation is not

*Bill Roehr; printed in EDN, May 5, 1979.

[1]Fred M. Blatt, *"Pick the Right 'Fast' Rectifiers to Design Switchers Effectively,"* EDN January 20, 1978.

much over 20 kHz, but the slower the diode, the higher the penalty in terms of switching losses in the transistors and a demand for transistors with higher safe operating area.

One problem in making a suitable selection is the lack of satisfactory test standards for very high speed rectifier diodes; consequently, switching data published in the literature sometimes yields contradictory results. A JEDEC standard does exist which is satisfactory for the 100 to 200 ns fast recovery rectifiers which have been on the market for years. The test conditions are set up to achieve a di/dt decay of forward current of 25 A/μs (far too slow to distinguish between Schottky and other ultra-fast devices currently available), and a peak forward current of 3 to 4 times the rectifier dc current rating (a desirable objective but not essential particularly if achieved at the expense of di/dt), but reverse voltage is not controlled (a source of serious error for Schottky devices which have a large junction capacitance). Users have also raised questions concerning overshoots observed during turn-on and are concerned that forward recovery may be an important but neglected factor in determining power losses. Also, since most Schottky devices are constructed with a p-n junction guard ring surrounding the Schottky barrier, questions have arisen concerning the validity of the assumption that reverse recovery time can be ignored because Schottkies are majority carrier devices.

Test Method For High Speed Rectifier Diodes

To resolve, or at least shed some light on these questions, a very fast high current test circuit was developed. It is shown schematically in Figure 1 and is similar in some respects to the power converter circuitry in which high speed rectifiers find use. For fastest speed it is important that the transistors be driven from a low impedance source such as complementary emitter followers. The R-C network in the collector sharpens up the leading edges of the current pulse while the Zener clamp permits a large flyback voltage to occur thereby sharpening up the falling edge. The values shown permit currents up to 50 A to be achieved with a falling di/dt of about 350 A/μs. Up to the point where transformer leakage and circuit inductance prevent faster di/dt from being achieved, collector circuit values can be altered to obtain various output currents and falling di/dt.

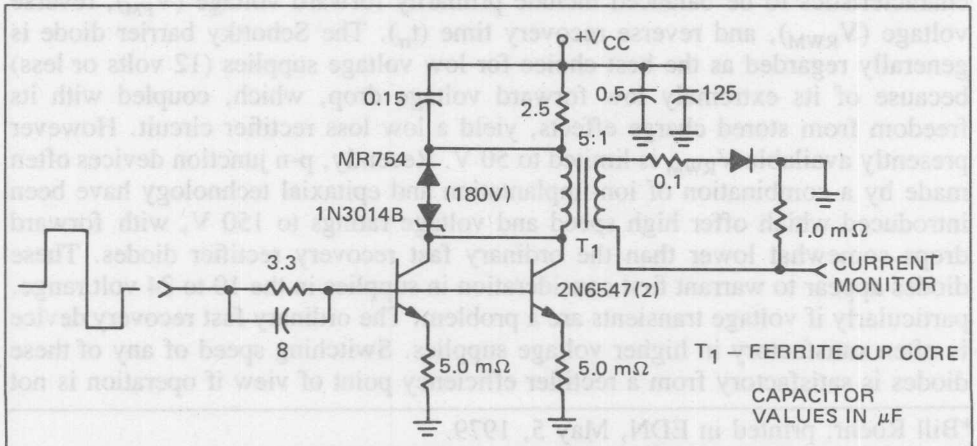
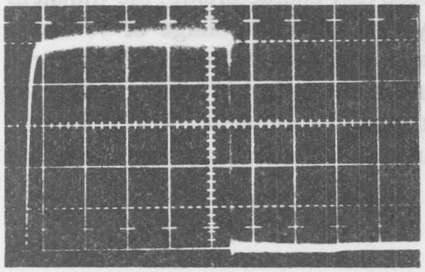


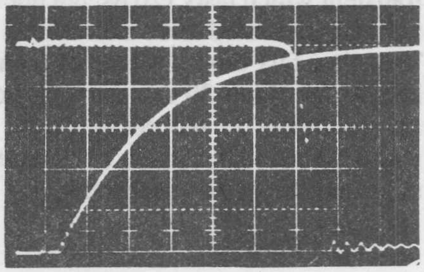
FIGURE 1 — Schematic of High Speed Test Fixture

Test Results

A 50 ampere diode current pulse is shown in Figure 2. The initial 20 amperes is achieved in about 0.2 μs, which is a di/dt of approximately 100 A/μs; similarly the fall time rate from 50 amperes is about 350 A/μs.



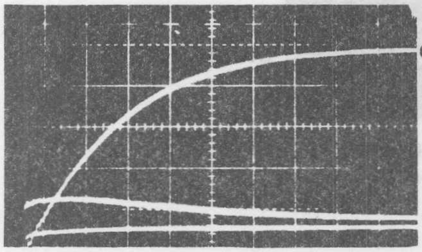
a) Overall Pulse
Time Scale: 5 μs/Div.



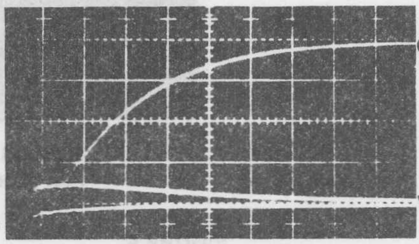
b) Rising and Falling Edges
Time Scale: 0.2 μs/Div.

FIGURE 2
Rectifier Current Waveforms from Circuit of Figure 1 with Schottky Diode Installed. Current Scale: 10 A/Div.

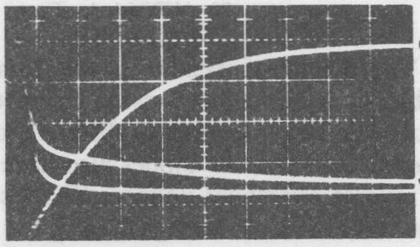
Figure 3 shows the turn-on current and voltage waveforms for three different diodes using the same horizontal and vertical scales. A peak voltage of about 1.3 volts is observed at the Schottky diode terminal (see "a" top voltage trace), but by placing the probe on top of the die (via a hole cut into the package), the overshoot is non-existent (see "a" lower trace). Therefore, the overshoot is caused entirely by lead inductance. Parts b and c show turn-on for an ultra-fast p-n diode and a conventional high voltage fast recovery p-n diode. Note that these devices exhibit some overshoot at the die, although the ultra-fast diode overshoot is small and barely discernible in the photo.



a) Schottky Diode



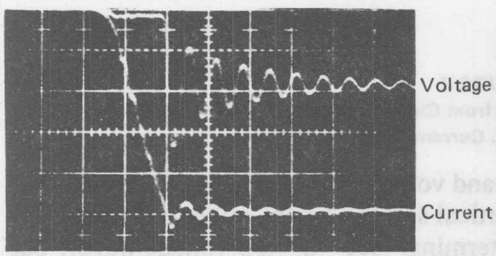
b) Ultra-Fast p-n Diode



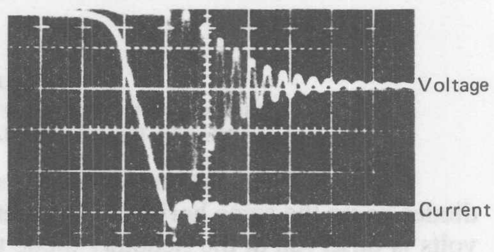
c) Standard Gold Diffused
Fast Recovery p-n Diode

FIGURE 3
Turn-on Waveforms of Various Diodes Showing Current, Voltage at Terminal, and Voltage at Top of Die. Current Scale: 10 A/Division. Voltage Scale: 1 Volt/Division. Time Scale: 0.2 μs/Division.

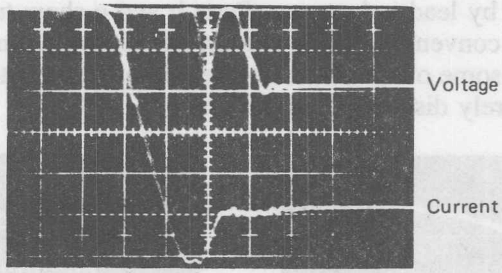
The reverse characteristics of the three types of diodes under consideration are shown in Figure 4. The differences in recovery characteristics are quite pronounced. The Schottky diode shows a peak reverse current of about 3 amperes coupled with some ringing; the peak reverse voltage generated is 60 volts. The conventional fast recovery device shows a 12 ampere reverse recovery current transient which lasts 120 ns; but due to its soft recovery characteristic, the transient voltage generated does not exceed the steady state reverse voltage of 40 volts. The ultra-fast diode, while only showing a peak recovery current of 3 amperes lasting for about 30 ns, causes a voltage transient of about 115 volts because of an abruptness in the decay of the reverse current. To prevent EMI problems, snubbing would normally be required. The snubber, of course, imposes additional stress on the drive transistors.



a) Schottky Diode



b) Ultra-Fast p-n Diode



c) Standard Gold Diffused Fast Recovery p-n Diode

FIGURE 4
Turn-off Waveforms of Various Diodes Showing Current Decay and Reverse Voltage Transients. Current Scale: 10 A/Division. Voltage Scale: 20 V/Division. Time Scale: 0.1 μs/Division.

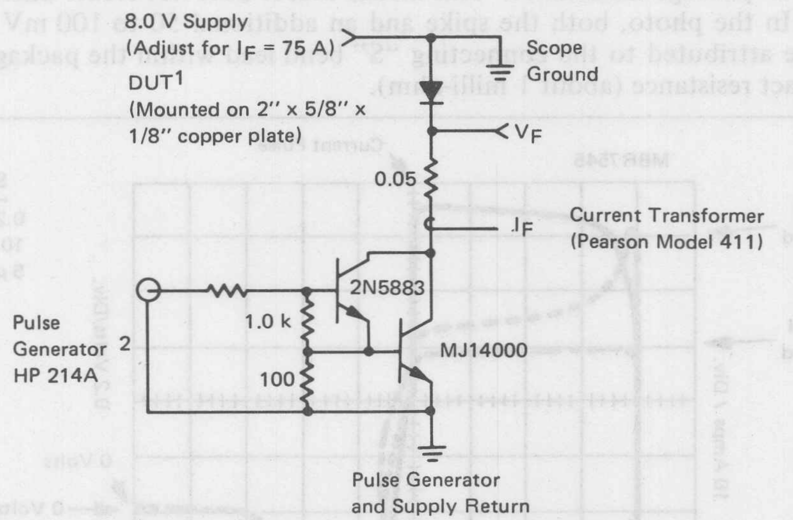
The results of these tests should not be interpreted as being generally applicable to a particular class of product, as different manufacturing techniques produce diodes with greatly different characteristics. For example, some conventional fast recovery diodes also have an abrupt current decay which produces high reverse overshoot voltage. The lesson here is rather that devices from different vendors, even though having the same part number, should be evaluated to discern their recovery characteristics and that fast recovery is not always synonymous with high reverse overshoot voltage.

RECTIFIER TEMPERATURE RISE TEST TELLS IT ALL!*

Introduction

Motorola recently ran some DO-5 rectifier tests in order to compare the performance characteristics of Schottkys, fast recovery and ion-implanted devices. Of particular concern was the forward recovery transient and how it might possibly make Schottkys less efficient than similar fast recovery rectifiers. The tests turned out to be very informative in several ways. First, it was shown that the 1 to 2.0 V forward recovery transient was due strictly to package inductance and was not a dissipative problem. Second, the test results showed that simple temperature rise measurements can be very useful in determining which device is the most efficient for a particular application.

Because of their low forward voltage drop (0.5 to 0.7 V), Schottkys are typically used instead of fast recovery rectifiers (0.8 to 1.0 V) as the rectifier elements for high current 5.0 V, 200 kHz, switchmode supplies. A single pair of Schottkys (70 A) could presently be used to provide up to 150 A to the load depending on the trade-offs available to the designer. In push-pull, bridge and forward converter supplies, the secondary voltage is about 8.0 V, and the rectifiers must block up to 30 V. Motorola's platinum Schottky blocking ratings now extend to 50 V at 150°C, so they would be adequate for most designs. However, the new lines of low voltage (100 V) fast recovery and ion-implanted devices are now becoming competitive (efficiency wise) in this area.



Notes: 1. Thermocouple embedded in 1/8" copper washer located between the package and the copper plate.

2. Generator output is 50 V, pulse width is adjusted for 20 µs diode current pulses and duty cycle of 4.0%.

FIGURE 1 — The Test Circuit

*R.J. Haver; printed in SOLID-STATE POWERCONVERSiON, May/June, 1978.

Test Philosophy

In order to provide a 75 A, 20 μs current pulse to the diodes under test, the diode, a load resistor and switching transistor were connected in series to an 8.0 V supply as shown in Figure 1. This 20 μs pulse simulates operation at 20 kHz, and turn-on transients can be observed in this circuit without scope grounding problems. To reduce load and power supply requirements, the duty cycle was reduced from 40% to 4%, and essentially no heat sinking was provided for the rectifiers under test. The case to ambient thermal resistance was about 12°C/Watt.

In order to duplicate an actual application, it would be necessary to provide reverse bias for about 20 μs following the current pulse. This was not desirable here since this study was concerned with the effects of the forward recovery transient (and not leakage) on efficiency.

The Forward Recovery Transient

In the test circuit, all devices exhibited a 1.2 V to 1.5 V forward recovery transient. In order to determine if this was characteristic of the die, a small ¼″ hole was made in the side of Motorola's MBR7545 Schottky rectifier (DO-5 package). With the scope probe in this location, no transient was observed. However, when the scope probe was moved to the connecting wire about ½″ from scope ground, an identical transient was observed. The test photo is shown in Figure 2. This test conclusively proved that the spike was due strictly to package inductance. This means that it does not create dissipative losses. In the photo, both the spike and an additional 50 to 100 mV of IR drop are attributed to the connecting "S" bend lead within the package and its contact resistance (about 1 milli-ohm).

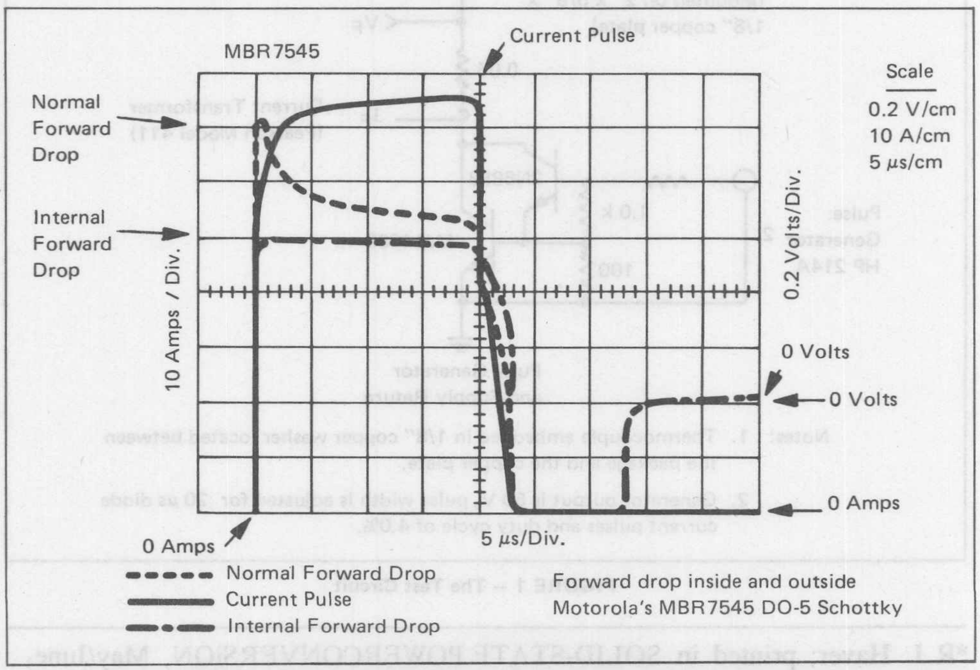


FIGURE 2

Package inductance is just a small part of the problem of busing high frequency, high current pulses from the secondary winding to the filter and load of a switchmode supply. A bigger part of this problem is attributed to the connecting lead inductance. In this test, the rise time of the 75 A current pulse with an 8.0 V supply was about 2.0 μs. The total series inductance is therefore about 200 nH, and because 15% of the voltage appeared across the diode, its inductance is only 15% of the total or about 30 nH. This agrees with a rule of thumb judgement for inductance of 1.0 μH per foot, and this current rise time is indeed typical of similar switchmode supplies. The conclusions are that diode inductance is relatively insignificant and that new techniques for busing such as twisted connecting wires should be considered where faster rise times are desirable.

Temperature Rise And Efficiency

The current pulse, rep rate and heat sinking were all kept constant during these tests. Therefore, the most efficient and the best device is the one with the lowest temperature rise. This discounts, as was stated earlier, the second order effect of power loss due to leakage currents. For the fast recovery devices and Motorola's platinum Schottkys, this is actually the case. However, some Schottky processes do have leakage and potential thermal runaway problems and should be analyzed further in this regard. The test results are shown graphically in Figure 3. A review of this data indicates that not all Schottkys are alike and that the fast recovery and ion-implanted rectifiers are still not quite as efficient as Schottkys.

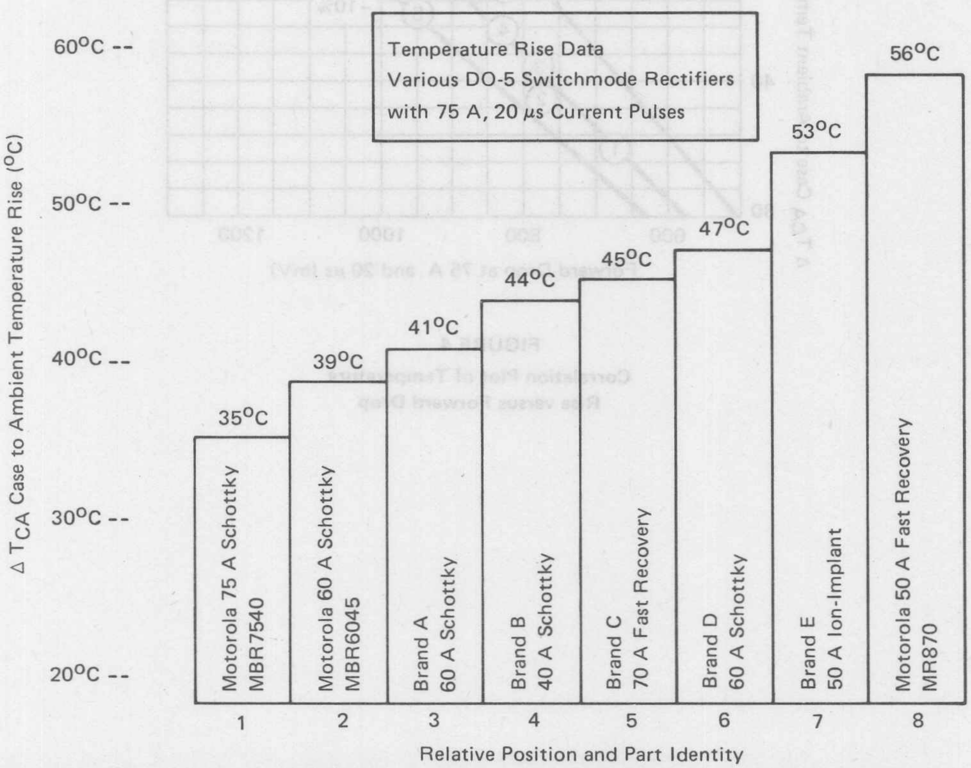


FIGURE 3

This data can also be used to estimate the temperature rise in an actual supply. As an example, if a 40% duty cycle and 1.2°C/Watt heat sinking are assumed instead of 4% and 12°C/Watt, the temperature rise would be quite similar, (actually it would be slightly higher due to reverse bias losses), and proportionately less heat sinking would produce proportionately higher rises. In all cases, two or three parts were checked to determine which were most typical. From any given manufacturer, the forward drops were very close (20 mV out of 700 to 800 mV). Since it was proved earlier that the forward recovery transient was lossless, then these termperature rises ought to correlate very well with forward drop. This turned out to be the case as is shown in Figure 4. Here, the forward drop of each device at the end of the 20 μs pulse was plotted against temperature rise, and the correlation was very good (+15%, −10%). This, of course, means that typical forward drops and forward drop specs are indeed quite significant to the designer. However, as was done here, temperature rise tests in an actual application are still the ultimate and the best test for efficiency.

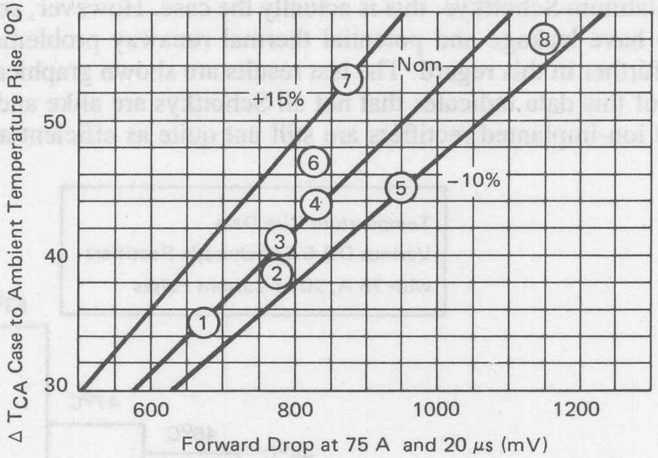


FIGURE 4
Correlation Plot of Temperature Rise versus Forward Drop

CHAPTER 15

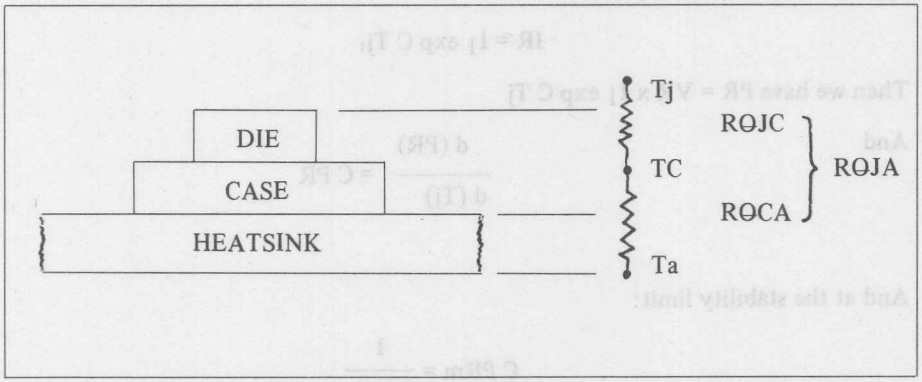
SCHOTTKY BARRIER THERMAL STABILITY

A power rectifier is a thermal system where it's important to know the stability limits. This system is constituted by:

– the heat source: the silicium die,

– the heat dissipation components : case and heatsink,

– the environnement where the temperature is supposed constant : Ta



STABILITY CONDITIONS

Power evacuated outside must be equal to the dissipated power in the die, then thermal stability equation is :

$$\frac{Tj - Ta}{R\Theta JA} = PF + PR\,(Tj)$$

With PF = dissipated power in forward conduction (quite independent of Tj)
PR = dissipated power in reverse (it is a function of Tj)

The condition of thermal stability is :

$$\frac{d\,PR\,(Tj)}{d\,Tj} < \frac{1}{R\Theta JA}$$

STABILITY LIMIT

In a diode, reverse current variation with temperature must be represented in first approximation by the equation :

$$IR = I_1 \exp C\,Tj;$$

Then we have $PR = VR \times I_1 \exp C\,Tj$

And

$$\frac{d\,(PR)}{d\,(Tj)} = C\,PR$$

And at the stability limit:

$$C\,PRm = \frac{1}{R\Theta JA}$$

At the stability limit, the value of the reverse current will be :

$$IRm = \frac{1}{C\ R\Theta JA\ VR}$$

Maximal junction temperature will be :

$$Tjm = \frac{1}{C} Ln \frac{IRm}{I_1}$$

And the maximal ambient temperature:

$$Tam = Tjm - PF\ R\Theta - \frac{1}{C}$$

For each value of TA < Tam, the diode will be thermally stable, the junction temperature value will be below Tjm and the leakage current IR lower than the limit value IRm.

For MOTOROLA diodes family, the value of C is quite constant ($\approx$ 0.05), it is therefore interesting to notice that maximal value of admissible IR is directly determined by use conditions.

NOTE: when the solution Θm we had is higher than Θj max value, we must consider that $\Theta m = \Theta j$ max.

And then $\Theta am = \Theta j\ max - R\Theta\ VR\ IRm$

With $IRm = IR$ at $\Theta = \Theta j\ max$

Example : for a mounting where the heatsink used is $R\Theta JA = 10^oC/W$ and where the reverse voltage applied is VR = 30 V, the running maximum IR admissible will be:

$$I_{Rm} = \frac{1}{0.05 \times 10 \times 30} = 66\ mA$$

A measure of this current made on the functionning circuit in the worst conditions of charge and ambient temperature will allow to evaluate the security edge with regard to this limit.

In this same application, if we use a diode with $I_R = 0.3$ mA (experimental measurement), the thermal stability limit temperature will be :

$$Tj = \frac{1}{0.05} \; Ln \, \frac{66}{0.3} = 108^oC$$

$$Ta\ max = 108^oC - PF \times 10$$

If forward dissipated power is PF = 2 Watts, the maximum ambient temperature will be :

$$Ta\ max = 88^oC$$

USE OF DATA SHEETS

MOTOROLA data sheets give diectly the graphic solution of the stability limit calculations that we just made.

Generally the running diode is not submitted to a continue reverse voltage but to a square or sinusoidal signal. The reverse voltage which must be consider is the equivalent VR voltage :

VR equi = VR peak x F
The Parameter F to use is given in the data sheets.

Therefore the average forward dissipated power value PF must be evaluated taking into account the average current value IF (AV) and the form of the signal.

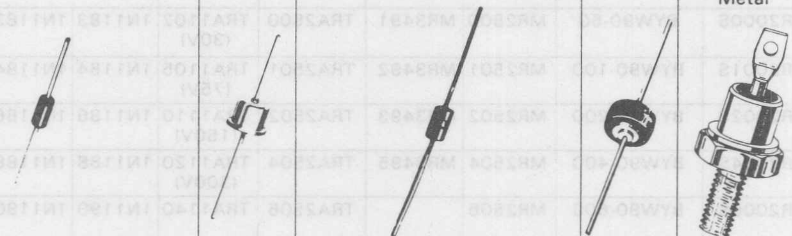
The set of curves presented in the data sheets allows to determine the ambient temperature Tam in two steps:

1. From VR and RΘ, evaluation of the parameter T_R
2. From TR and PF, determine Tam value

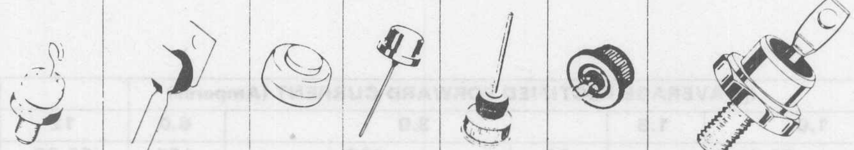
RECTIFIERS

General-Purpose Rectifiers

Motorola offers a wide variety of low-cost devices, packaged to meet diverse mounting requirements. Of particular interest are plastic "buttons", *such as the* MR2500 *series, designed for clip or recessed mounting, and the new* plastic chassis mounts, *derived from these buttons, types* MR2000S *and* BYW90. *All listed lines are available with anode-to-case connection by adding "R" suffix to the standard part number.*



	I_O, AVERAGE RECTIFIED FORWARD CURRENT (Amperes)								
	1.0		1.5	3.0				6.0	12
	59-04			60 Metal	267 Plastic			194 Plastic	56-02 (DO-4) Metal
V_{RRM} Volts									
50	1N4001		BY601	1N4719	MR500	1N5400		MR750	MR1120 1N1199B
100	1N4002		BY602	1N4720	MR501	1N5401		MR751	MR1121 1N1200B
200	1N4003	BY135	BY603	1N4721	MR502	1N5402	BY251	MR752	MR1122 1N1202B
400	1N4004		BY604	1N4722	MR504	1N5404	BY252	MR754	MR1124 1N1204B
600	1N4005	BY126/134	BY605	1N4723	MR506	1N5406	BY253	MR756	MR1126 1N1206B
800	1N4006		BY606	1N4724	MR508	1N5407	BY254	MR758	MR1128
1000	1N4007		BY607	1N4725	MR510	1N5408		MR760	MR1130
1300		BY127/133	BY608				BY255		
I_{FSM} (Amps)	30	40	50	300	100	200	100	400	300
T_A @ Rated I_O (°C)	75	75	T_L = 70	75	95	T_L = 105	85	60	
T_C @ Rated I_O (°C)									150
T_J(Max) (°C)	175	150	175	175	175	175	175	175	190

I_O, AVERAGE RECTIFIED FORWARD CURRENT (Amperes)									
20	24	25				35	40		
283-01 (DO-4) Plastic	339 Plastic Note 1	193-03 Plastic	43-05	273-01	043-05		257-01 (DO-5) Metal		
								Note 2	V_{RRM} Volts
MR2000S	BYW90-50	MR2500	MR3491	TRA2500	TRA1102 (30V)	1N1183	1N1183A	40HF05	50
MR2001S	BYW90-100	MR2501	MR3492	TRA2501	TRA1105 (75V)	1N1184	1N1184A	40 HF10	100
MR2002S	BYW90-200	MR2502	MR3493	TRA2502	TRA1110 (150V)	1N1186	1N1186A	40HF20	200
MR2004S	BYW90-400	MR2504	MR3495	TRA2504	TRA1120 (300V)	1N1188	1N1188A	40HF40	400
MR2006S	BYW90-600	MR2506		TRA2506	TRA1140	1N1190	1N1190A	40HF60	600
MR2008S	BYW90-800	MR2508		TRA2508		1N3766	CF	40HF80	800
MR2010S	BYW90-1000	MR2510		TRA2510		1N3768	CF	40HF100	1000
									1300
400	400	400		400	400	400	800	500	I_{FSM} (Amps)
									T_A @ Rated I_O (°C)
150	125	150	130	150	120	140	150	140	T_J(Max) (°C)
175	175	175	175	175	175	190	190	190	T_C @ Rated I_O (°C)

NOTES: 1. Meets mounting configuration of TC-220 outline.
▲ Request Data Sheet for Mounting Information
CF: Consult Factory
2. 40HF Series available with metric threads (4[illegible]M) and/or flexible braid lead (41HF, 41HFM)

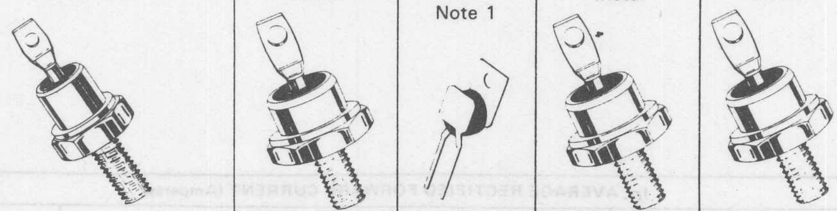
Fast Recovery Rectifiers

. . . available for designs requiring a power rectifier having maximum switching times ranging from 200 ns to 750 ns. These devices are offered in current ranges of 1.0 to 50 amperes and in voltages to 1000 volts. Higher voltages are available upon request, but a necessary trade-off against switching speeds results. Reverse polarity (anode to case) obtained by adding an "R" suffix.

Fast Recovery Rectifiers are also available in full-wave bridge and high current multicell configurations.

V_{RRM} (Volts)	I_O, AVERAGE RECTIFIED FORWARD CURRENT (Amperes)						
	1.0		3.0				5.0
	59-04 Plastic 		60 Metal 	267-01 Plastic 			194 Plastic 
50	1N4933	MR810	MR830	MR850	MR910		MR820
100	1N4934	MR811	MR831	MR851	MR911	BY500 −100	MR821
200	1N4935	MR812	MR832	MR852	MR912	BY500 −200	MR822
400	1N4936	MR814	MR834	MR854	MR914	BY500 −400	MR824
600	1N4937	MR816	MR836	MR856	MR916	BY500 −600	MR826
800		MR817			MR917		
1000		MR818			MR918		
I_{FSM} (Amps)	30	30	100	100	100	200	300
T_A @ Rated I_O	75	75		90*	90*	25	55*
T_C @ Rated I_O (°C)			100				
T_J(Max) (°C)	150	150	150	175	175	175	175
t_{rr} (μs)	0.2	0.75	0.2	0.2	0.75	0.3	0.2

* Must be derated for reverse power dissipation. See Data Sheet.

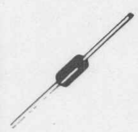
I_O, AVERAGE RECTIFIED FORWARD CURRENT (Amperes)						
6.0	12	20	24	30	50	
56.02 (DO-4) Metal		257 (DO-5) Metal	339 Plastic Note 1	257 (DO-5) Metal	257 (DO-5) Metal	
						V_{RRM} (Volts)
1N3879	1N3889	1N3899	BYW91-50	1N3909	MR870	50
1N3880	1N3890	1N3900	BYW91-100	1N3910	MR871	100
1N3881	1N3891	1N3901	BYW91-200	1N3911	MR872	200
1N3883	1N3893	1N3903	BYW91-400	1N3913	MR874	400
MR1366	MR1376	MR1386	BYW91-600	MR1396	MR876	600
						800
						1000
150 300*	200 300*	250	300	300	400	I_{FSM} (Amps)
						T_A @ Rated I_O
100	100	100	125	100	100	T_C @ Rated I_O (°C)
150	150	150	175	150	160	T_J(Max) (°C)
0.2	0.2	0.2	0.2	0.2	0.2	t_{rr} (μs)

NOTE 1: Meets mounting configuration of TO-220 outline.

JAN/JANTX available

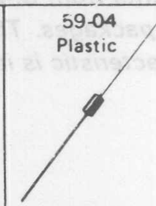
Fast recovery Rectifiers

... available for consumer applications requiring currents from 0.4A up to 3A in low cost axial lead packages. Their "soft recovery" characteristic is ideal for TV usages.

	I_O, AVERAGE RECTIFIED FORWARD CURRENT (Amperes)							
	0.4	**0.5**	**0.8**	**1**	**1.2**		**2**	**3**
Case	59-04						267 Plastic	
								
V_{RRM} (Volts)								
50								
100					BY196		BY296	BY396
200					BY197		BY297	BY397
400	BA157	BY206	BY406	BY210-4	BY198	BYX55-350	BY298	BY398
600	BA158	BY207	BY407	BY210-6		BYX55-600		
800				BY210-8	BY199		BY299	BY399
1000	BA159							
I_{FSM} (Amp)	30	30		30	40	40	100	100
T_A@ Rated I_O °C	45	45		75	50	50	90	90
T_J Max °C	150	150		175	150	125	150	175
t_{rr} (ns)	500	600		750	500	600	500	400

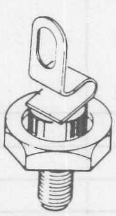
Special Purpose Rectifiers

250 mA High Voltage Diodes	
Case	169-02 Plastic 
V_{RRM} (Volts)	
1000	MR250-1
2000	MR250-2
3000	MR250-3
4000	MR250-4
5000	MR250-5
I_{FSM} (Amps)	15
T_A @ Rated I_O (^oC)	75
T_J (Max) (^oC)	150

1.0 Ampere Television Damper Diode	
Case	59-04 Plastic 
V_{RRM} (Volts)	
1000	MR1-1000
1200	MR1-1200
1400	MR1-1400
1600	MR1-1600
I_{FSM} (Amps)	30
T_A @ Rated I_O (^oC)	75*
T_J (Max) (^oC)	175
t_{rr} (μs)	25

*Must be derated for reverse power dissipation. See Data Sheet.

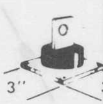
1.0 Ampere High Voltage Rectifiers	
Case	59-04 
V_{RRM} Volts	
1000 V	MR1-1000
1200 V	MR1-1200
1400 V	MR1-1400
1600 V	MR1-1600 BYX10
I_{FSM} (A)	30
T_A @ Rated I_O °C	75
T_J Max °C	175
t_{rr} μs	25

Avalanche Rectifier		
Case	296-03 	194 
V_{RRM} (Volts)		
23	MR2525	MR2525L
23	MR2525R	
I_O (Amp)	25	6
BV (Volts)	24-32	24-32
I_{RSM} (Amp)	62	62
I_{FSM} (Amp)	600	600
T_C @ Rated I_O (^oC)	150	150
T_{JRRM} (^oC)	175	175

High-Current Multi-Cell Rectifiers

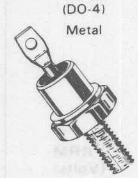
Multi-Cell construction, with matched cells, for excellent thermal management and highest reliability. Normally available with cathode connected to case. Add "R" suffix to type number for reverse polarity.

Fast Recovery and Schottky versions are available by consulting the factory.

	I_O, AVERAGE RECTIFIED FORWARD CURRENT			
	100A		450A	700A
V_{RRM} (Volts)	 10-32 Stud 1-1/4" Hex Case 167	 3/8" Stud 1-1/4" Hex Case 189	 3/4" Stud 2-1/4" Hex Case 128  3" 3" Case 135	 3-1/4" 3-1/4" Case 136
300	MR1215FL	MR1815SL	MR1245SL, FL	MR1265FL
600	MR1219SL	MR1819SL	MR1249SL, FL	MR1269FL
I_{FSM} (Amp)	2000	2000	8000	12000
T_C @ Rated I_O (°C)	135	135	150	150
T_J (Max) (°C)	190	190	190	190

Schottky Rectifiers

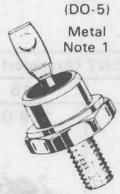
Refinements in processing of SWITCHMODE Schottky Power Rectifiers are producing ruggedness and temperature performance comparable to silicon-junction rectifiers, with the high speed and low forward voltage drop characteristic of Schottky's metal/silicon junctions. Ideal for use in low voltage, high frequency power supplies and as very fast clamping diodes, these devices feature switching times less than 10 ns, and are offered in current ranges from 0.5 to 75 amperes, and reverse voltages to 50 Volts. Higher currents multicell, full-wave bridge and reverse polarity (anode to case) versions are available by consulting the factory.

	I_O, AVERAGE RECTIFIED FORWARD CURRENT (Amperes)											
	0.5	1.0		3.0		3.0	5.0	15		25		
V_{RRM} (Volts)	51-02 (DO-7) Glass 	59-04 Plastic 		267 Plastic 		60 Metal 		56-02 (DO-4) Metal 				
20	††MBR020	1N5817	MBR120P	1N5820	MBR320P	MBR320M	1N5823	1N5826	MBR1520	1N5829	MBR2520	
30		1N5818	MBR130P	1N5821	MBR330P	MBR330M	1N5824	1N5827	MBR1530	1N5830	MBR2530	1N6095
35						MBR335M			MBR1535		MBR2535	
40		1N5819	MBR140P	1N5822	MBR340P	MBR340M	††N5825	1N5828	MBR1540	†1N5831	MBR2540	1N6096
45												
I_{FSM} (Amps)	5.0	25	25	80	80	500	500	500	500	800	800	400
†T_C @ Rated I_O (°C)								85	80	85	80	70
T_A @ Rated I_O PC Board Mount (°C)	50											
†T_L @ Rated I_O (°C)		90	80	95	85	90	80					
T_J (Max) (°C)	125	125	125	125	125	125	125	125	125	125	125	125
Max V_F @ $I_{FM} = I_O$	0.50 $T_L = 25°C$	*0.60 $T_L = 25°C$	*0.60 $T_L = 25°C$	*0.525 $T_L = 25°C$	0.55 $T_L = 25°C$	0.45 @ 5 A $T_C = 25°C$	*0.38 $T_C = 25°C$	*0.50 $T_C = 25°C$	0.55 $T_C = 25°C$	*0.48 $T_C = 25°C$	0.55 $T_C = 25°C$	0.86@78.5A $T_C = 70°C$

* Values are for the 40-Volt units. The lower voltage parts provide lower limits.

† Must be derated for reverse power dissipation. See Data Sheet.

†† Motorola TX versions available, consult factory.

I_O, AVERAGE RECTIFIED FORWARD CURRENT (Amperes)											
30	35		40			50	60		75		
54 (TO-3) Metal 	56-02 (DO-4) Metal 		257 (DO-5) Metal Note 1 		430-2 (DO-21) Metal 		257 (DO-5) Metal Note 1 				V_{RRM} (Volts)
MBR3020CT	MBR3520	BYS35-20	1N5832	MBR4020	MBR4020PF		MBR6020	BYS60-20	BYS75-20	MBR7520	20
	.	BYS35-30	1N5833	MBR4030	MBR4030PF	1N6097		BYS60-30	BYS75-30	MBR7530	30
MBR3035CT	MBR3535			MBR4035	MBR4035PF		MBR6035			MBR7535	35
SD241	SD41		1N5834	MBR4040	MBR4040PF	1N6098	SD51			MBR7540	40
MBR3045CT	†MBR3545	BYS35-45					†MBR6045	BYS60-45	BYS75-45	†MBR7545	45
		BYS35-50						BYS60-50	BYS75-50		50
400	600	600	800	800	800	800	800	800	1000	1000	I_{FSM} (Amps)
95	90	90	75	70	50	70	90	90	90	90	†T_C @ Rated I_O (°C)
											T_A @ Rated I_O PC Board Mount (°C)
											†T_L @ Rated I_O (°C)
150	150	150	125	125	125	125	150	150	150	150	T_J (Max) (°C)
0.95 @ 60A T_C = 125°C	0.70@78.5A T_C = 125°C	0.77@70A T_C = 100°C	*0.59 T_C = 25°C	0.63 T_C = 25°C	0.63 T_C = 25°C	0.86@157A T_C = 70°C	0.80@157A T_C = 125°C	0.81@120A T_C = 100°C	0.78@150A T_C = 100°C	0.90@220A T_C = 125°C	Max V_F @ I_{FM} = I_O

Capable of 150°C junction temperature operation.

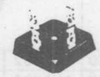
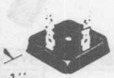
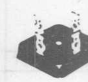
NOTES: 1. Braided lead top terminal configuration available; consult your Sales Representative.

†Motorola TX versions available, consult factory.

Rectifier Bridges

Motorola SUPERBRIDGES offer cost effectiveness and reliability in single phase applications. Chip/leadframe techniques are used for lower-current types, while the higher current assemblies combine pretested "button" rectifier cells for low assembly cost and high yields. Performance of four individual diodes is achieved at the cost of only two, with reliability of the whole assembly comparable to that of a single unit. The higher current assemblies feature versatile slip-on/solder/wire wrap terminals.

Fast Recovery versions having reverse recovery times of less than 200 nanoseconds are available by adding a "FR" suffix to the part number.
Schottky Bridge inquiries are invited by the factory.

	I_O, DC OUTPUT CURRENT (Amperes)						
	1.5	**1.0**	**2.0**	**4.0/8.0***	**15**	**25**	**35**
	109-03	312-02	312-02	117A-01 Note 1	309-01	309A-03	309-01
							
V_{RRM} Volts							
50	MDA920A2	MDA100A	MDA200	MDA970A1	BYW20	BYT25-50	BYW60
100	MDA920A3	MDA101A	MDA201	MDA970A2	BYW21	BYT25-100	BYW61
200	MDA920A4	MDA102A	MDA202	MDA970A3	BYW22	BYT25-200	BYW62
400	MDA920A6	MDA104A	MDA204	MDA970A5	BYW24	BYT25-400	BYW64
600	MDA920A7	MDA106A	MDA206		BYW26	BYT25-600	BYW66
800	MDA920A8	MDA108A	MDA208	CF	BYW28	BYT25-800	BYW68
1000	MDA920A9	MDA110A	MDA210	CF	BYW79	BYT25-1000	BYW89
I_{FSM} (Amp)	45	30	60	100	400	400	400
T_A @ Rated I_O (°C)	50	75	55	•			
T_C @ Rated I_O (°C)				•	100	55	55
T_J(Max) (°C)	175	150	175	150	175	175	175

*4.0 A @ T_A = 25°C
8.0 A @ T_C = 55°C

Note: 1. The MDA970A series replaces the MDA 970 in the new Case 117A-01, which has minor changes over the old Case 117. (Effective 3 Q 79.)
SUPERBRIDGES is a trademark of Motorola Inc.

MOTOROLA

1N 1183, A thru 1N 1190, A
1N 3766, 1N 3768

STUD MOUNTED POWER RECTIFIER

. . . compact, highly efficient silicon rectifier for medium current applications requiring:

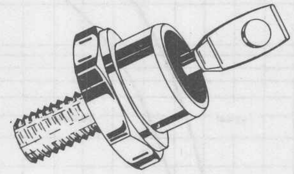
— High Current Surge —500 to 800 Amperes
— Peak performance at elevated temperatures

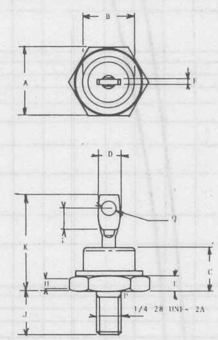
Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

STUD MOUNTED POWER RECTIFIERS

50–1000 VOLTS
35, 40 AMPERES





DIM	MILLIMETERS min.	MILLIMETERS max	INCHES min	INCHES max
A	16.91	17.45	0.667	0.687
B	-	16.94	-	0.667
C	-	11.43	-	0.450
D	-	9.53	-	0.375
E	2.92	5.08	0.115	0.200
F	-	2.03	-	0.080
H	1.52	-	0.060	-
J	10.72	11.51	0.422	0.453
K	-	25.40	-	1.000
L	3.86	-	0.152	-
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

CASE 257
DO-5

MAXIMUM RATINGS

Rating	Symbol	IN 1183 A	IN 1184 A	IN 1186 A	IN 1188 A	IN 1190 A	IN 3766	IN 3768	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non repetitive Peak Reverse Voltage	V_{RSM}	75	150	275	500	725	950	1200	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts

IN 1183 thru IN 1190, IN 3766, IN 3768

Rating	Symbol	Value	Unit
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^o$ C)	I_O	35	Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	500 (one cycle)	Amp

IN 1183 A thru IN 1190 A

Rating	Symbol	Value	Unit
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^o$ C)	I_O	40	Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	800 (one cycle)	Amp
Operating Junction Temperature Range	T_J	–65 to +200	^{o}C
Storage Temperature Range	T_{stg}	–65 to +200	^{o}C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Typ	Max	Unit
Thermal Resistance, Junction to Case IN 1183 IN 1183 A	$R_{\theta JC}$	0,9 0,7	1,0 0,9	^{o} C/W ^{o} C/W

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Instantaneous Forward Voltage 1 N 1183 A (I_F = 100 Amp., $T_J = 150^o$ C) 1 N 1183	V_F	1.10 1.30	Volts
Reverse Current (rated dc voltage) $T_C = 25^o$ C $T_C = 100^o$ C	I_R	100 0,5	µA mA

MECHANICAL CHARACTERISTICS

CASE: Welded hermetically sealed

FINISH: All external surfaces corrosion resistant and readily solderable

POLARITY: Cathode to Case

WEIGHT: 17 Grams (Approximately)

STUD TORQUE: 25 in. lb. max.

FIGURE 1 – FORWARD VOLTAGE

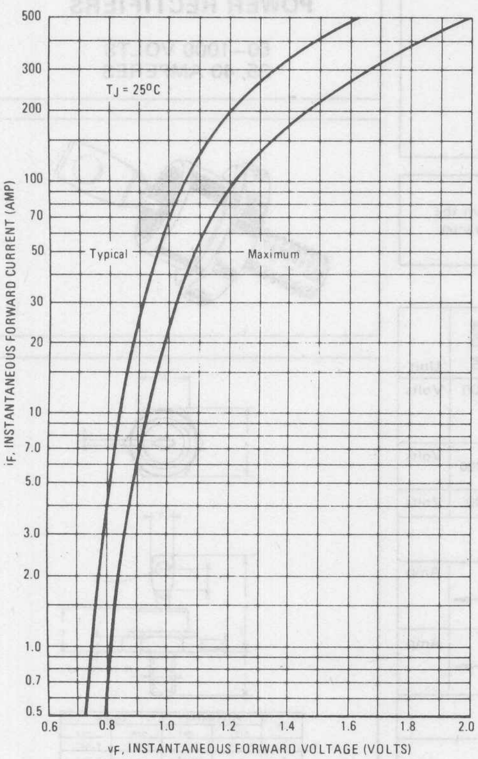


FIGURE 2 – MAXIMUM SURGE CAPABILITY

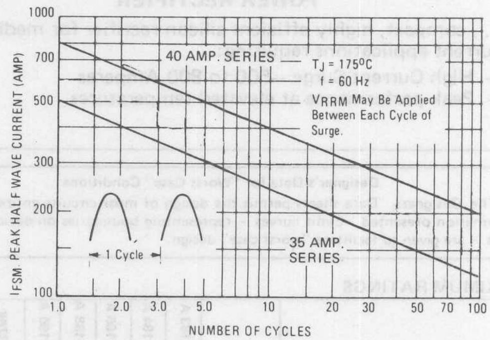


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

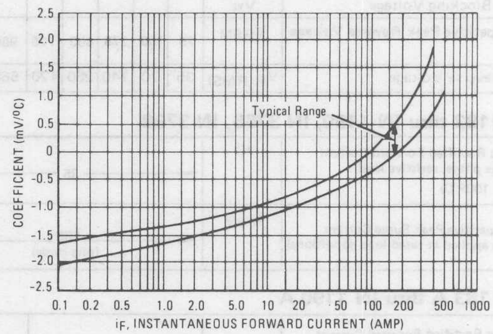


FIGURE 4 – CURRENT DERATING

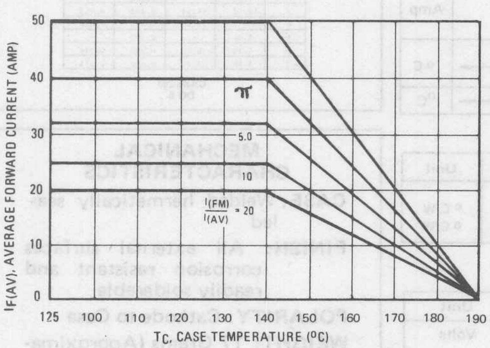


FIGURE 5 – FORWARD POWER DISSIPATION

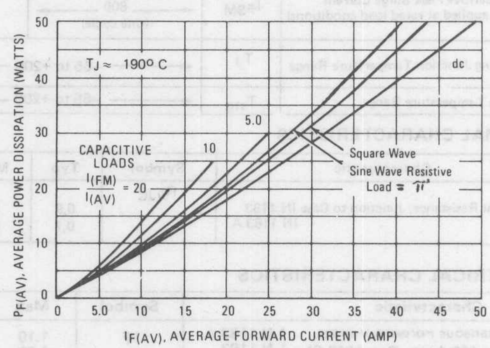
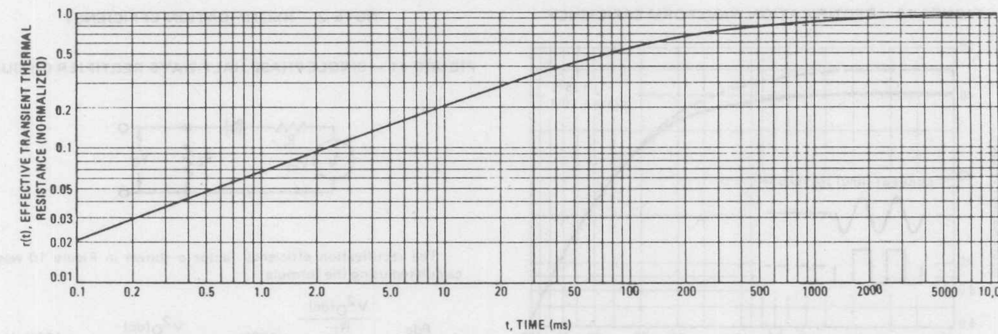
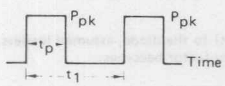


FIGURE 6 – THERMAL RESPONSE



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} \left[D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1) \right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

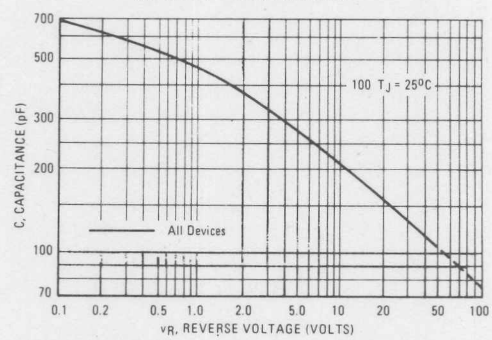


FIGURE 8 – FORWARD RECOVERY TIME

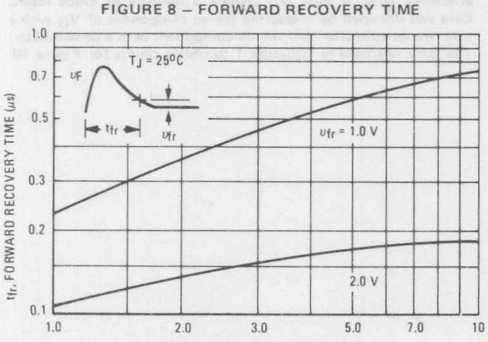


FIGURE 9 – REVERSE RECOVERY TIME

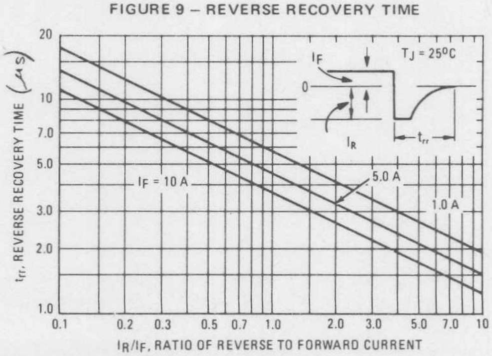
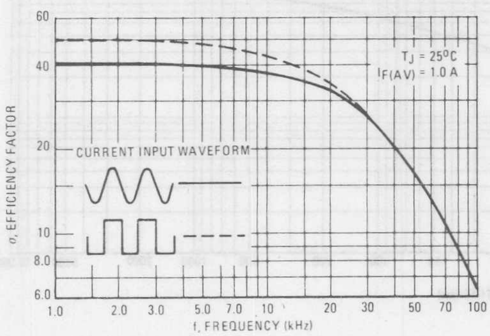
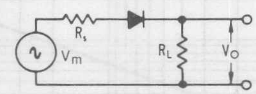


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY



NOTE 2 – RECTIFICATION EFFICIENCY

FIGURE 11 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\dfrac{V^2_{O(dc)}}{R_L}}{\dfrac{V^2_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2_{O(dc)}}{V^2_{O(ac)} + V^2_{O(dc)}} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assumed lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\dfrac{V^2_m}{\pi^2 R_L}}{\dfrac{V^2_m}{4R_L}} \bullet 100\% = \frac{4}{\pi^2} \bullet 100\% = 40.6\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\dfrac{V^2_m}{2R_L}}{\dfrac{V^2_m}{R_L}} \bullet 100\% = 50\% \quad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 10.

It should be emphasized that **Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses.** Data was obtained by measuring the ac component of V_O with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

MOTOROLA

1 N 1199 B thru 1 N 1206 B 1 N 3988 1 N 3990

MEDIUM-CURRENT SILICON RECTIFIERS

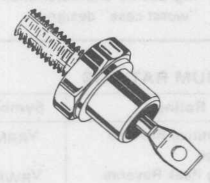
Compact, highly efficient silicon rectifiers for medium-current applications requiring:

- High Current Surge — 250 Amperes @ $T_J = 200°C$
- Peak Performance at Elevated Temperature — 12 Amperes @ $T_C = 150°C$

MEDIUM-CURRENT SILICON RECTIFIERS

50–1000 VOLTS
12 AMPERES

DIFFUSED JUNCTION



MAXIMUM RATINGS

Characteristic	Symbol	1N1199 B	1N1200 B	1N1202 B	1N1204 B	1N1206 B	1N3988	1N3990	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz peak)	V_{RSM}	100	200	350	600	800	1000	1200	Volts
Average Rectified Forward Current (Single phase, resistive load, 60 Hz, $T_C = 150°C$)	I_O	← 12 →							Amp
Non-Repetitive Peak Surge Current (surge applied @ rated load conditions, half wave, single phase, 60 Hz)	I_{FSM}	← 250 (for 1 cycle) →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -65 to +200 →							°C

*THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	2.0	°C/W

*ELECTRICAL CHARACTERISTICS

Characteristic and Conditions	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage ($i_F = 40$ A, $T_C = 25°C$)	v_F	1.2	Volts
Maximum Reverse Current (Rated dc voltage, $T_C = 150°C$)	I_R	1.0	mA
Maximum Average Reverse Current at Rated Conditions	I_{RO}	0.9	mA
DC Forward Voltage ($I_F = 12$ A, $T_C = 25°C$)	V_F	1.1	Volts
Reverse Recovery Time ($I_{FM} = 40$ A, $di/dt = 25$ A/µs to $I_{FM} = 0$, $t_p \geqslant 4.0$ µs, 60 pulses/second, 25°C)	t_{rr}	5.0	µs

*Indicates JEDEC registered data.

MECHANICAL CHARACTERISTICS

Case: Metal hermetically sealed

Finish: All external surfaces are corrosion-resistant and the terminal lead is readily solderable

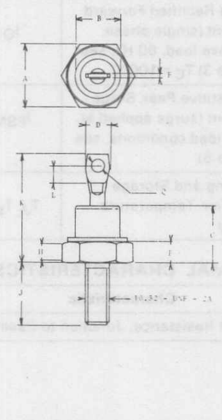
Polarity: Cathode to case (reverse polarity units are available and designed by an "R" suffix, i.e., 1N1202RB)

Mounting Positions: Any

Stud Torque: 15 in/lbs max

Maximum Terminal Temperature for Soldering Purposes: 275°C for 10 seconds at 3 kg tension.

Weight: 6 grams (approx)



DIM	MILLIMETERS min.	MILLIMETERS max.	INCHES min.	INCHES max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

DO - 4
CASE 56

MOTOROLA

1N3491 thru 1N3495
MR327 MR330
MR328 MR331

SILICON RECTIFIERS
25 AMPERE

50-1000 VOLTS
DIFFUSED JUNCTION

MEDIUM-CURRENT SILICON RECTIFIERS

. . . compact, highly efficient silicon rectifiers for medium-current applications.

Designer's Data for "Worst Case" Conditions

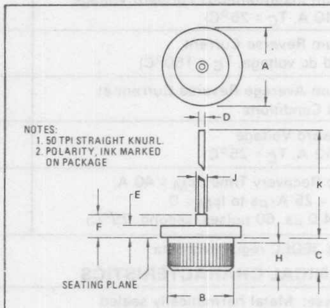
The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves — representing device characteristics boundaries — are given to facilitate "worst case" design.

*MAXIMUM RATINGS

Rating	Symbol	1N3491	1N3492	1N3493	1N3494	1N3495	MR327	MR328	MR330	MR331	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	500	600	800	1000	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	350	420	560	700	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz, see Figure 3) $T_C = 100°C$	I_O	← 25 →									Amp
Nonrepetitive Peak Surge Current (surge applied at rated load conditions, see Figure 5)	I_{FSM}	← 300 (for 1/2 cycle) →									Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -65 to +175 →									°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.2	°C/Watt



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	15.494	16.256	0.610	0.640
B	12.725	12.827	0.501	0.505
C	5.08	6.35	0.200	0.250
D	1.193	1.346	0.047	0.053
E	2.032	4.826	0.080	0.190
F	–	10.77	–	0.424
H	4.572	6.350	0.180	0.250
J	–	3.556	–	0.140
K	12.70	–	0.500	–

CASE 43-02
DO-21

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed construction.

FINISH: All external surfaces corrosion-resistant and the terminal lead is readily solderable.

POLARITY: CATHODE TO CASE (reverse polarity units are available upon request and are designated by an "R" suffix i.e. MR327R or 1N3491R).

MOUNTING POSITIONS: Any.

*Indicates JEDEC registered data for 1N3491–1N3495

*ELECTRICAL CHARACTERISTICS

Characteristic and Conditions	Symbol	Max	Unit
Instantaneous Forward Voltage Drop (i_F = 57 Amps, T_J = 25°C)	v_F	1.7	Volts
Full Cycle Average Reverse Current (18 Amp AV and V_r, single phase, 60 Hz, T_C = 150°C)	$I_{R(AV)}$		mA
1N3491		10	
1N3492		10	
1N3493		8.0	
1N3494		6.0	
1N3495		4.0	
MR327		3.0	
MR328		2.5	
MR330		2.0	
MR331		1.5	
DC Reverse Current (Rated V_R, T_C = 25°C)	I_R	1.0	mA

FIGURE 1 — MAXIMUM FORWARD VOLTAGE DROP

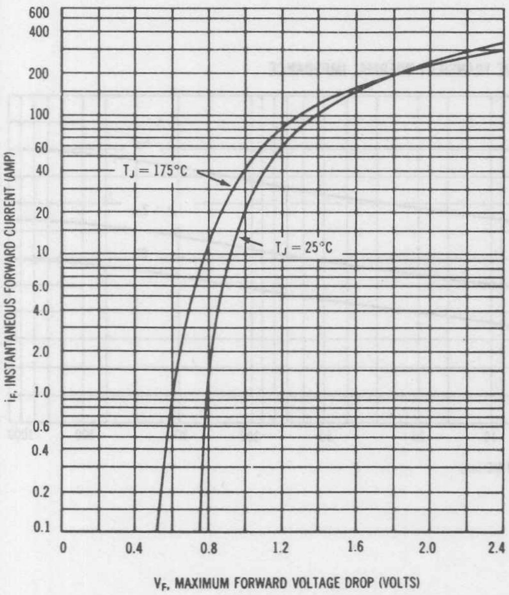


FIGURE 2 — MAXIMUM FORWARD POWER DISSIPATION

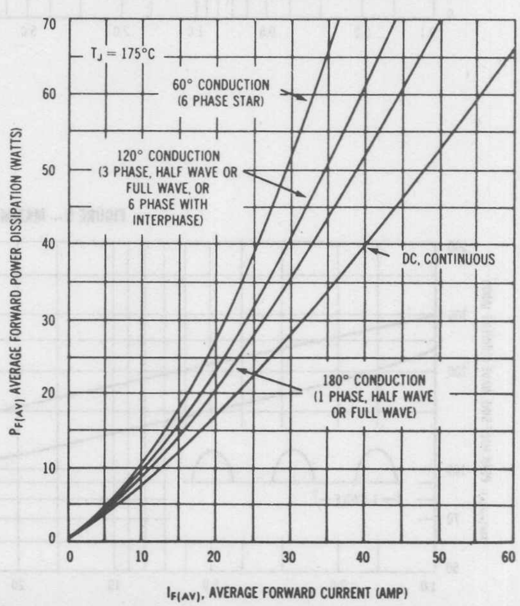


FIGURE 3 — MAXIMUM CURRENT RATINGS

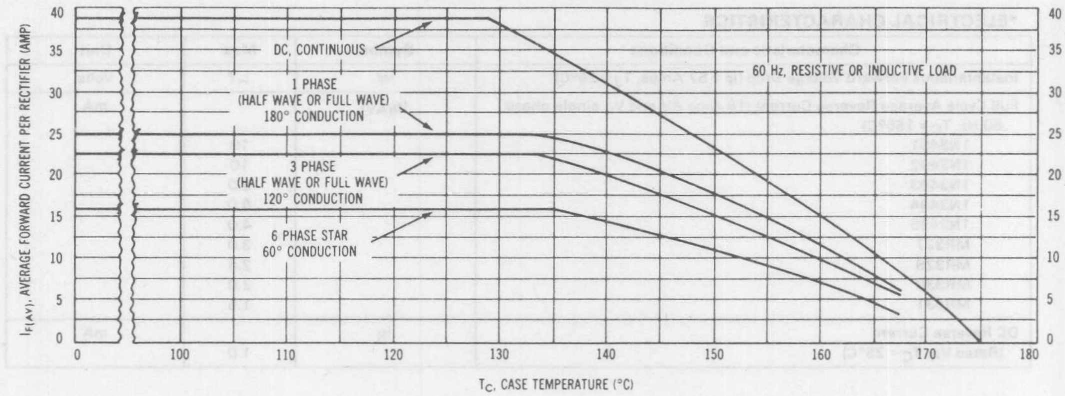


FIGURE 4 — MAXIMUM EFFECTIVE TRANSIENT THERMAL IMPEDANCE

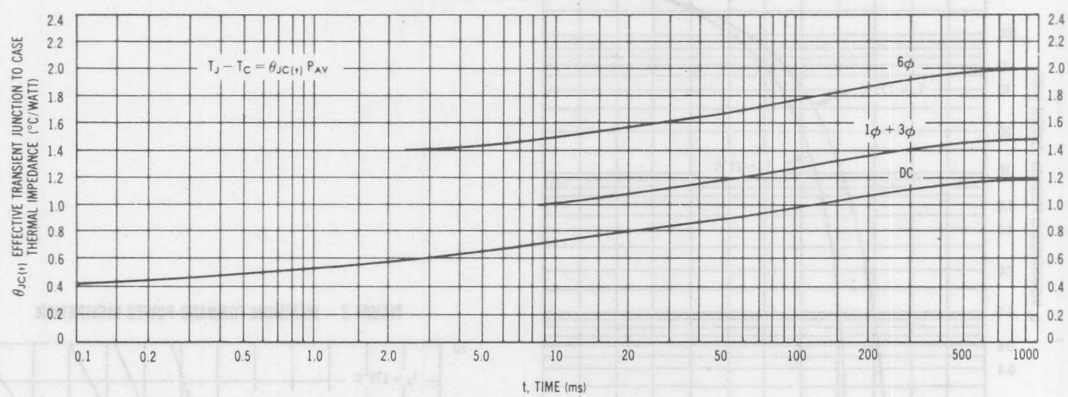
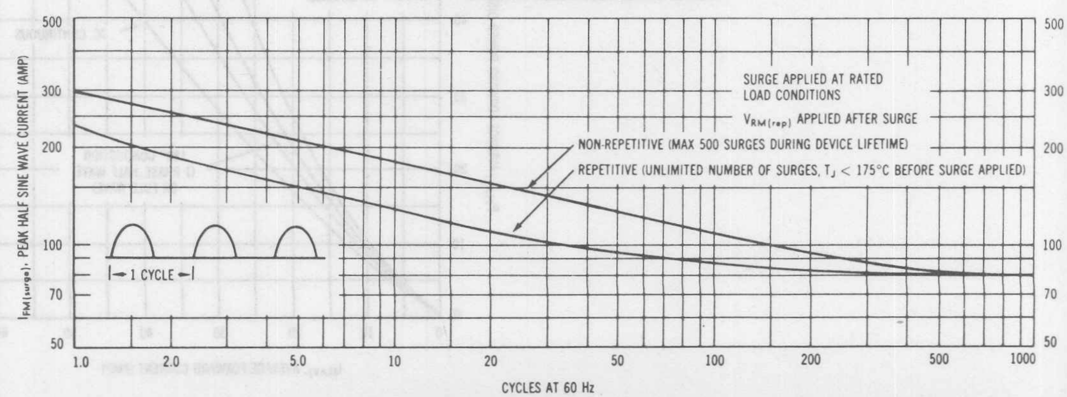


FIGURE 5 — MAXIMUM ALLOWABLE SURGE CURRENT



TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 6 — RECTIFICATION EFFICIENCY

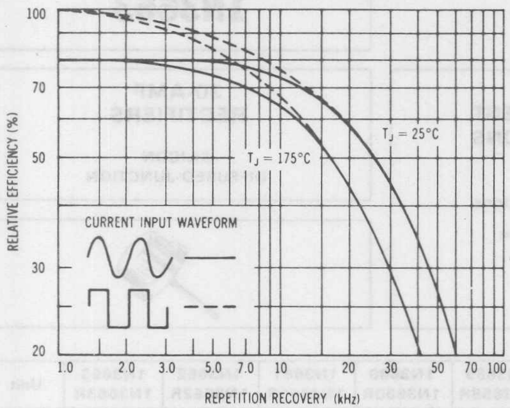


FIGURE 7 — REVERSE RECOVERY TIME

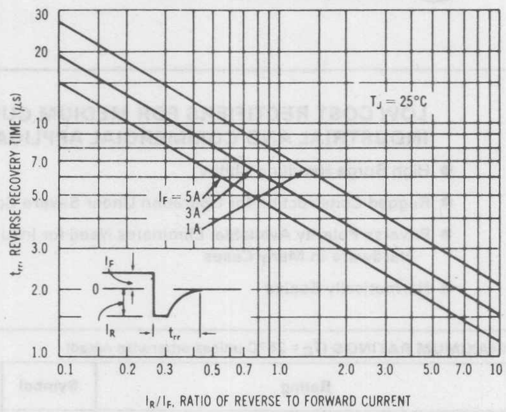


FIGURE 8 — JUNCTION CAPACITANCE

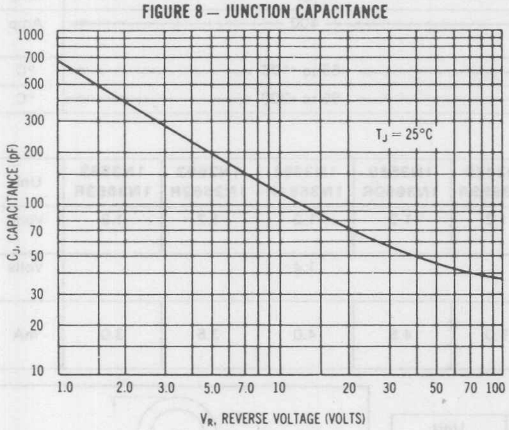
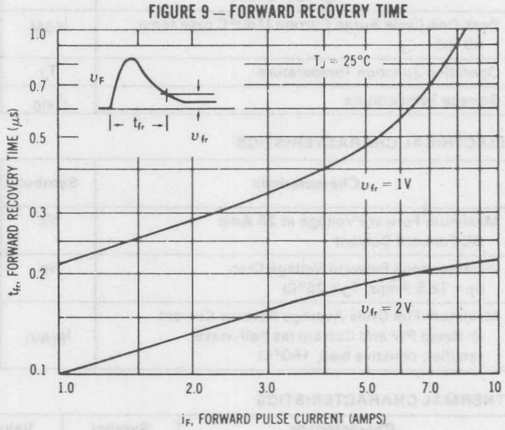
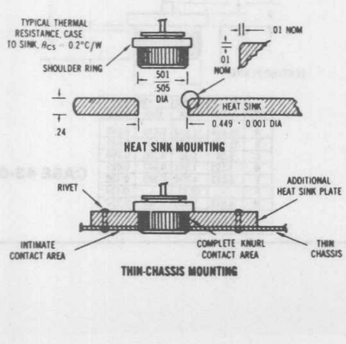


FIGURE 9 — FORWARD RECOVERY TIME





MOUNTING PROCEDURES

MR327-MR331 and 1N3491-1N3495 rectifiers are designed to be press-fitted in a heat sink in order to attain full device ratings. Recommended procedures for this type of mounting are as follows:

1. **Drill a hole in the heat sink 0.499 ± .001 inch in diameter.**
2. **Break the hole edge as shown to prevent shearing off the knurled edge of the rectifier when it is pressed into the hole.**
3. **The depth and width of the break should be 0.010 inch maximum to retain maximum heat sink surface contact.**
4. **To prevent damage to the rectifier during press-in, the pressing force should be applied only on the shoulder ring of the rectifier case as shown in the figure.**
5. **The pressing force should be applied evenly about the shoulder ring to avoid tilting or canting of the rectifier case in the hole during the press-in operation. Also, the use of a light industrial lubricant will be of considerable aid.**

1N3659 thru 1N3663

MOTOROLA

30-AMP RECTIFIERS

SILICON DIFFUSED-JUNCTION

LOW COST RECTIFIERS FOR MEDIUM CURRENT INDUSTRIAL AND COMMERCIAL APPLICATIONS

- High Surge Handling Ability
- Rugged Construction for Operation Under Severe Conditions
- Reverse Polarity Available; Eliminates Need for Insulation Hardware in Many Cases
- Hermetically Sealed

*MAXIMUM RATINGS (T_C = 25°C unless otherwise noted)

Rating	Symbol	1N3659 1N3659R	1N3660 1N3660R	1N3661 1N3661R	1N3662 1N3662R	1N3663 1N3663R	Unit
Peak Repetitive Reverse Voltage DC Blocking Voltage	V_{RRM} V_R	50	100	200	300	400	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	Volts
Average Half-Wave Rectified Forward Current with Resistive Load @ 100°C case @ 150°C case	I_O	← 30 → ← 25 →					Amp Amp
Peak One Cycle Surge Current (150°C case temp, 60 Hz)	I_{FSM}	← 400 →					Amp
Operating Junction Temperature	T_J	← −65 to +175 →					°C
Storage Temperature	T_{stg}	← −65 to +200 →					°C

*ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	1N3659 1N3659R	1N3660 1N3660R	1N3661 1N3661R	1N3662 1N3662R	1N3663 1N3663R	Unit
Maximum Forward Voltage at 25 Amp DC Forward Current	V_F	1.2	1.2	1.2	1.2	1.2	Volts
Instantaneous Forward Voltage Drop (i_F = 78.5 Amps, T_J = 25°C)	v_F			1.4			Volts
Maximum Full Cycle Average Reverse Current @ Rated PIV and Current (as half-wave rectifier, resistive load, 150°C)	$I_{R(AV)}$	5.0	4.5	4.0	3.5	3.0	mA

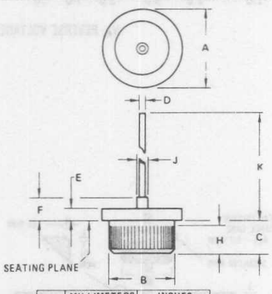
*THERMAL CHARACTERISTICS

Characteristic	Symbol	Value	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.2	°C/W

*Indicates JEDEC registered data.

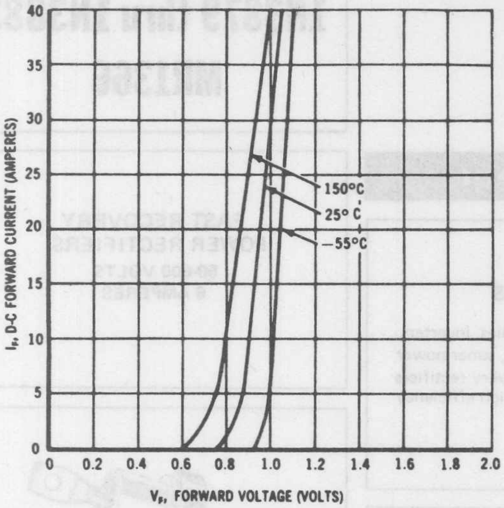
MECHANICAL CHARACTERISTICS

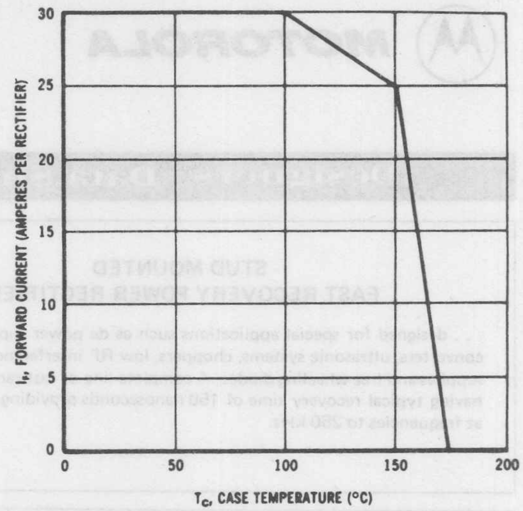
CASE: Welded hermetically sealed construction
FINISH: All external surfaces corrosion resistant, terminals readily solderable
WEIGHT: 9 grams (approx.)
POLARITY: Cathode connected to case (reverse polarity available denoted by Suffix R, i.e.: 1N3660R)
MOUNTING POSITION: Any



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	15.494	16.256	0.610	0.640
B	12.725	12.827	0.501	0.505
C	5.08	6.35	0.200	0.250
D	1.193	1.346	0.047	0.053
E	2.032	4.826	0.080	0.190
F	–	10.77	–	0.424
H	4.572	6.350	0.180	0.250
J	–	3.556	–	0.140
K	12.70	–	0.500	–

CASE 43-02



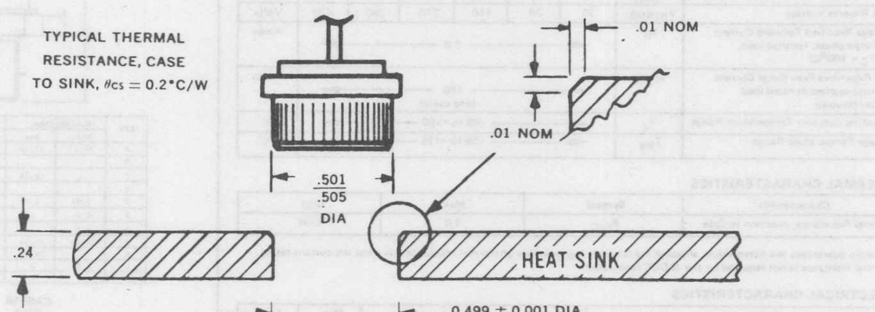


1N3659-1N3663 rectifiers are designed for press-fitted mounting in a heat sink. Recommended procedures for this type of mounting are as follows:

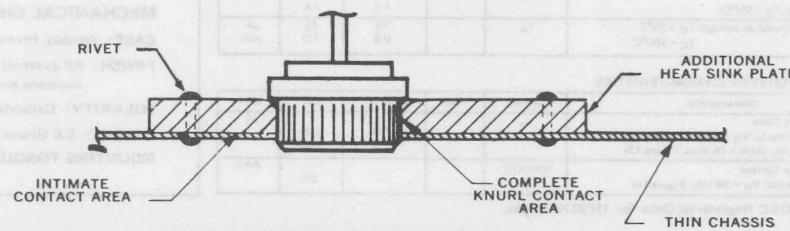
1. Drill a hole in the heat sink 0.499 ± .001 inch in diameter.
2. Break the hole edge as shown to prevent shearing off the knurled edge of the rectifier when it is pressed into the hole.
3. The depth of the break should be 0.010 inch maximum to retain maximum heat sink surface contact with the knurled rectifier surface.
4. Width of the break should be 0.010 inch as shown.

These procedures will allow proper entry of the rectifier knurled surface, provide good rectifier-heat sink surface contact, and assure reliable rectifier operation. If the break is made too deep, thereby reducing contact area for heat transfer, reliability of operation will be impaired.

These devices can be mounted in a thin chassis by inserting the rectifier through an additional heat sink plate which is mounted in intimate contact with the upper side of the chassis. This provides additional contact area for the rectifier knurled edge, as well as additional heat sink capacity.



HEAT SINK MOUNTING



THIN-CHASSIS MOUNTING

MOTOROLA

1N3879 thru 1N3883
MR1366

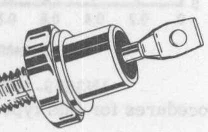
Designers Data Sheet

STUD MOUNTED
FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference, sonar power supplies and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

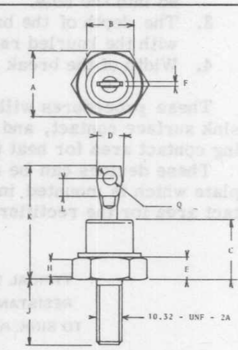
FAST RECOVERY POWER RECTIFIERS

50-600 VOLTS
6 AMPERES



Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.



DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56
DO-4

*MAXIMUM RATINGS

Rating	Symbol	1N3879	1N3880	1N3881	1N3882	1N3883	MR1366	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	350	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^oC$)	I_O	← 6.0 →						Amps
Non-Repetitive Peak Surge Current (surge applied at rated load continuous)	I_{FSM}	← 150 → (one cycle)						Amps
Operating Junction Temperature Range	T_J	← -65 to +150 →						^oC
Storage Temperature Range	T_{stg}	← -65 to +175 →						^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	3.0	$^oC/W$

Motorola guarantees the listed value, although parts having higher values of thermal resistance will meet the current rating. Thermal resistance is not required by the JEDEC registration.

*ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (i_F = 19 Amp, $T_J = 150^oC$)	v_F	–	1.2	1.5	Volts
Forward Voltage (I_F = 6.0 Amp, $T_C = 25^oC$)	V_F	–	1.0	1.4	Volts
Reverse Current (rated dc voltage) $T_C = 25^oC$ $T_C = 100^oC$	I_R	– –	10 0.5	15 1.0	μA mA

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time *(I_{FM} = 1.0 Amp to V_R = 30 Vdc, Figure 16) (I_{FM} = 36 Amp, di/dt = 25 A/μs, Figure 17)	t_{rr}	– –	150 200	200 400	ns
Reverse Recovery Current *(I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16)	$I_{RM(REC)}$	–	–	2.0	Amp

*Indicates JEDEC Registered Data for 1N3879 Series.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and readily solderable

POLARITY: Cathode to Case

WEIGHT: 5.6 Grams (approximately)

MOUNTING TORQUE: 15 in-lbs max.

FIGURE 1 – FORWARD VOLTAGE

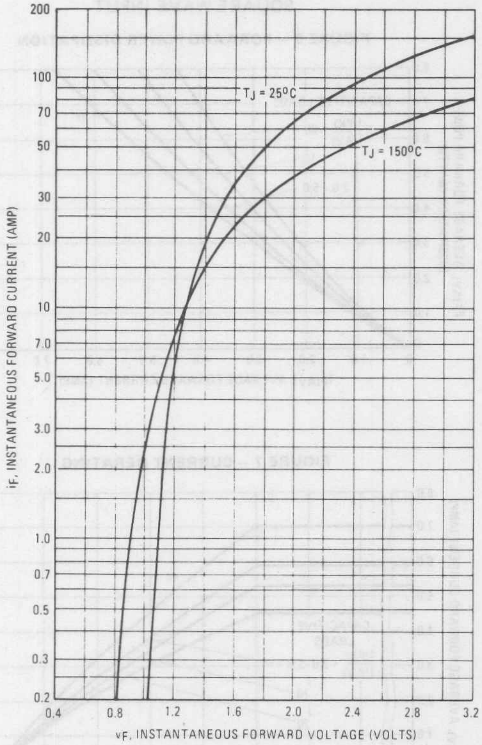
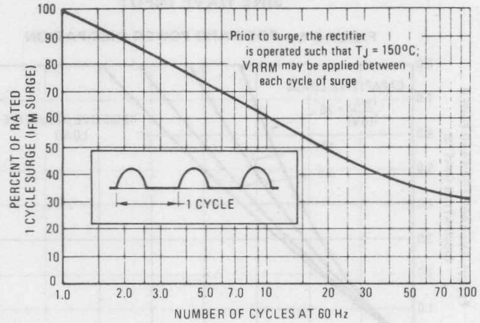
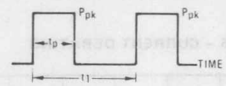


FIGURE 2 – MAXIMUM SURGE CAPABILITY



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by

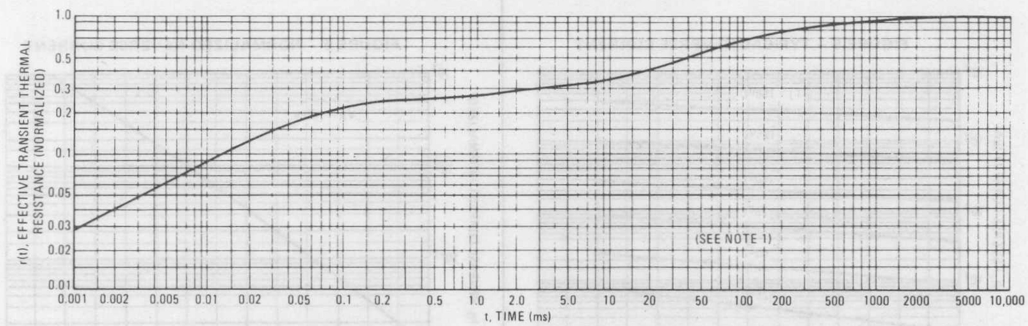
$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 3, i.e.

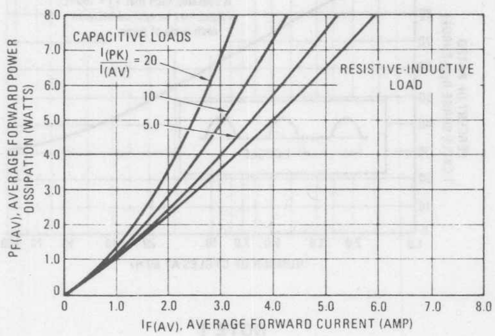
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

FIGURE 3 – THERMAL RESPONSE



SINE WAVE INPUT

FIGURE 4 – FORWARD POWER DISSIPATION



SQUARE WAVE INPUT

FIGURE 5 – FORWARD POWER DISSIPATION

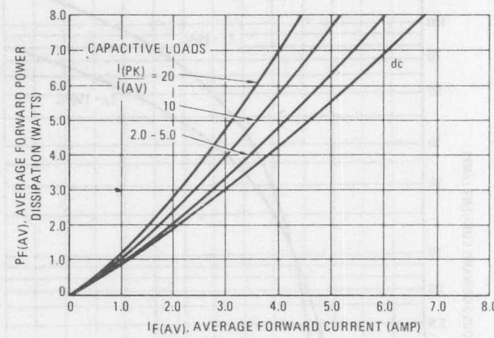


FIGURE 6 – CURRENT DERATING

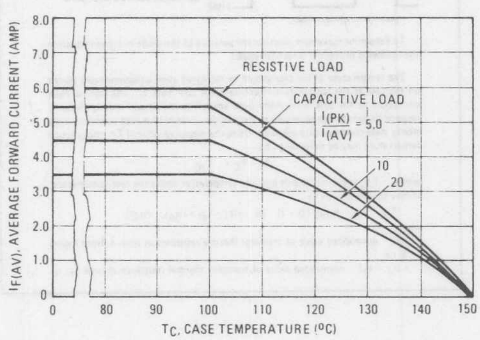


FIGURE 7 – CURRENT DERATING

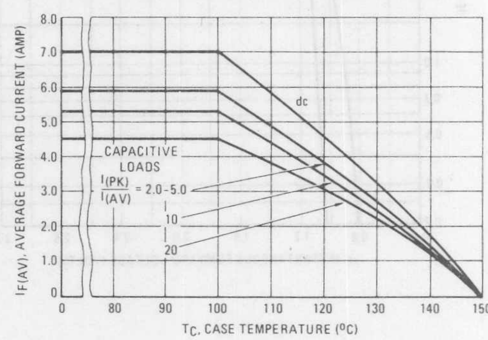


FIGURE 8 – TYPICAL REVERSE CURRENT

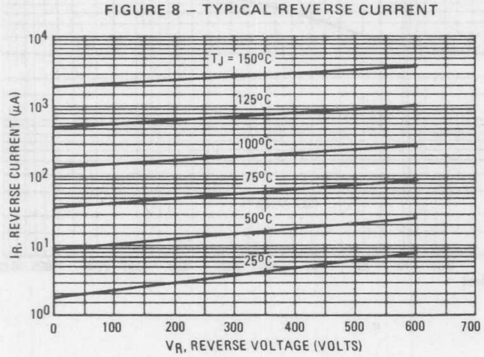
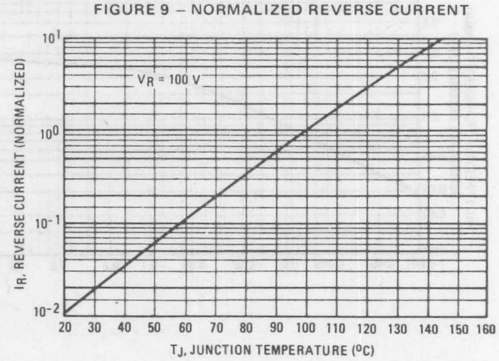


FIGURE 9 – NORMALIZED REVERSE CURRENT



TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 10 – FORWARD RECOVERY TIME

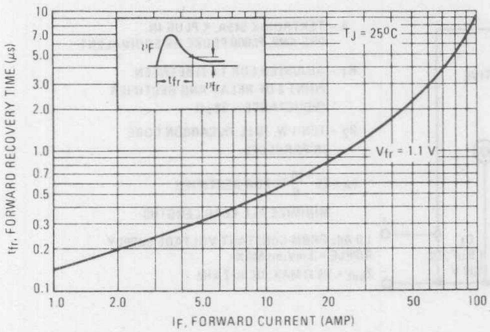
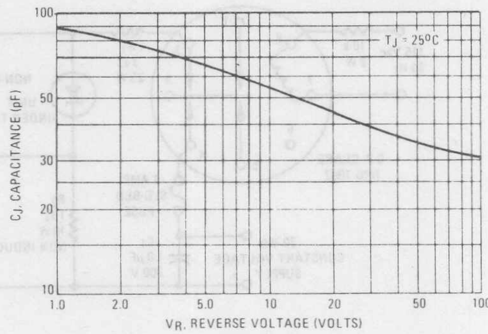


FIGURE 11 – JUNCTION CAPACITANCE



TYPICAL RECOVERED STORED CHARGE DATA

(SEE NOTE 2)

FIGURE 12 – $T_J = 25^oC$

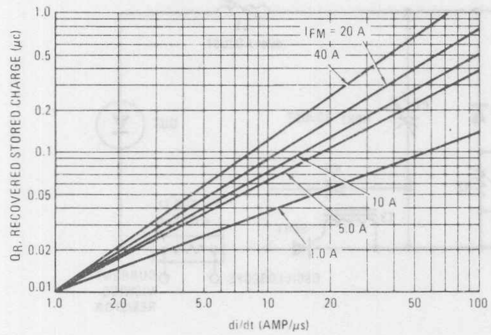


FIGURE 13 – $T_J = 75^oC$

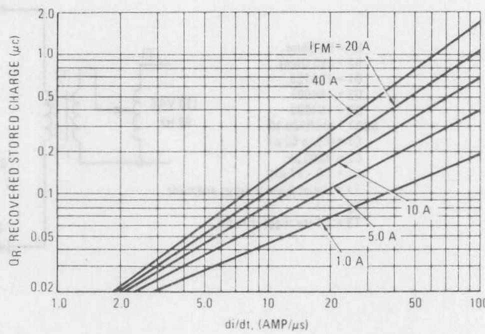


FIGURE 14 – $T_J = 100^oC$

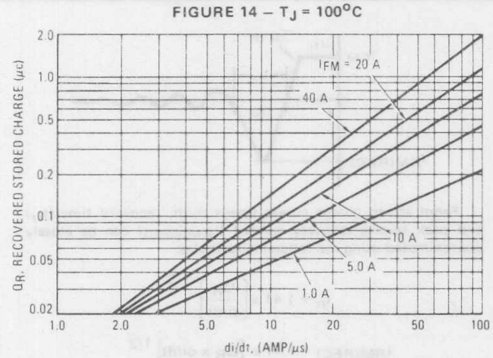


FIGURE 15 – $T_J = 150^oC$

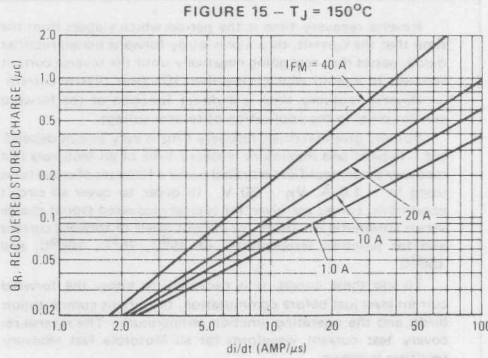
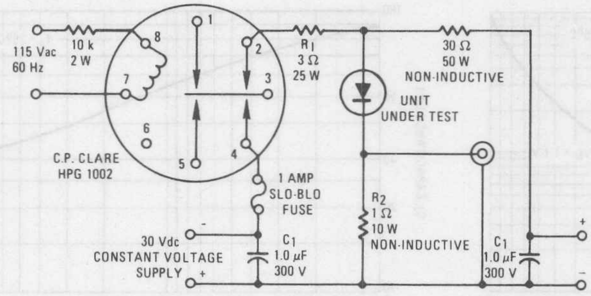


FIGURE 16 – REVERSE RECOVERY CIRCUIT



A – TEKTRONIX 545A, K PLUG IN PRE-AMP, P6000 PROBE OR EQUIVALENT

R_1 – ADJUSTED FOR 1.4 Ω BETWEEN POINT 2 OF RELAY AND RECTIFIER INDUCTANCE ≈ 38 μH

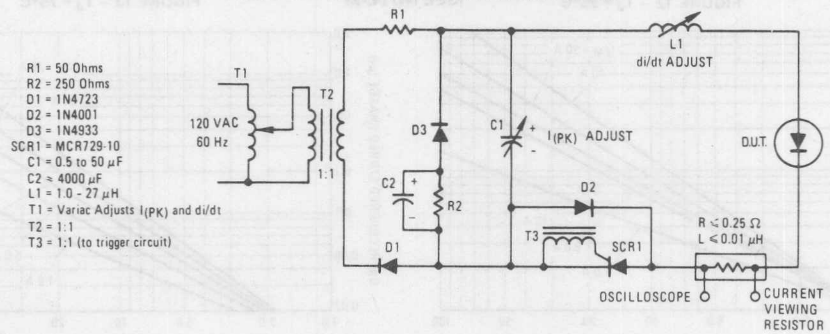
R_2 – TEN-1 W, 10 Ω, 1% CARBON CORE IN PARALLEL

$T_A = 25^{+10}_{-0}$ °C FOR RECTIFIER

MINIMIZE ALL LEAD LENGTHS

1.0 Adc FROM CONSTANT VOLTAGE SUPPLY
RIPPLE = 3 mVrms MAX
Z_{out} = 1½ Ω MAX, DC to 2 kHz

FIGURE 17 – JEDEC REVERSE RECOVERY CIRCUIT



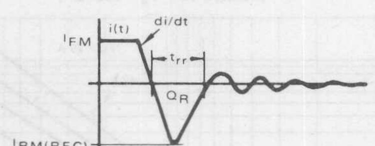
NOTE 2

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

MOTOROLA

1N3889 thru 1N3893
MR1376

Designers Data Sheet

STUD MOUNTED
FAST RECOVERY POWER RECTIFIERS

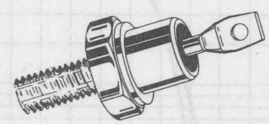
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference, sonar power supplies and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

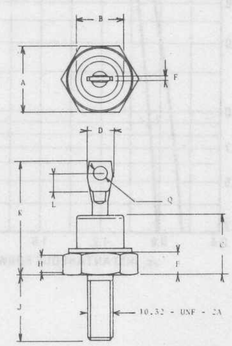
Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

FAST RECOVERY
POWER RECTIFIERS

50-600 VOLTS
12 AMPERES





DIM	MILLIMETERS min.	MILLIMETERS max.	INCHES min.	INCHES max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.025	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56
DO-4

*MAXIMUM RATINGS

Rating	Symbol	1N3889	1N3890	1N3891	1N3892	1N3893	MR1376	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	350	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^{\circ}C$)	I_O	← 12 →						Amps
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions)	I_{FSM}	← 200 (one cycle) →						Amp
Operating Junction Temperature Range	T_J	← -65 to +150 →						°C
Storage Temperature Range	T_{stg}	← -65 to +175 →						°C

THERMAL CHARACTERISTICS

Characteristics	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	2.0	°C/W

Motorola guarantees the listed value, although parts having higher values of thermal resistance will meet the current rating. Thermal resistance is not required by the JEDEC registration.

*ELECTRICAL CHARACTERISTICS

Characteristic		Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage ($i_F = 38$ Amp, $T_J = 150^{\circ}C$)		v_F	–	1.2	1.5	Volts
Forward Voltage ($I_F = 12$ Amp, $T_C = 25^{\circ}C$)		V_F	–	1.0	1.4	Volts
Reverse Current (rated dc voltage)	$T_C = 25^{\circ}C$ $T_C = 100^{\circ}C$	I_R	– –	10 0.5	25 3.0	μA mA

*REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time ($I_F = 1.0$ Amp to $V_R = 30$ Vdc, Figure 16) ($I_{FM} = 36$ Amp, di/dt = 25 A/μs, Figure 17)	t_{rr}	 – –	 150 200	 200 400	ns
Reverse Recovery Current ($I_F = 1.0$ Amp to $V_R = 30$ Vdc, Figure 16)	$I_{RM(REC)}$	–	–	2.0	Amp

*Indicates JEDEC Registered Data for 1N3889 Series.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and readily solderable

POLARITY: Cathode to Case

WEIGHT: 5.6 grams (approximately)

MOUNTING TORQUE: 15 in-lbs max.

FIGURE 1 – FORWARD VOLTAGE

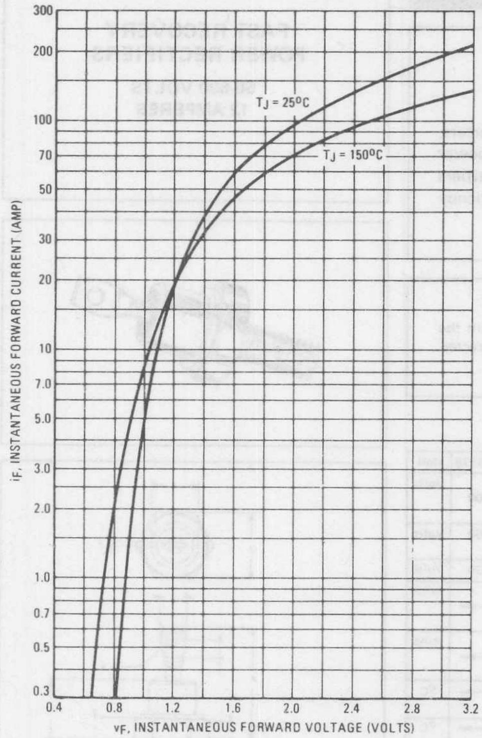
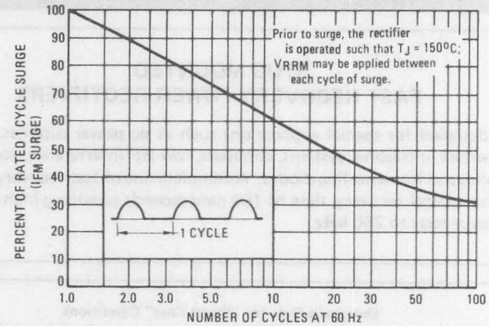
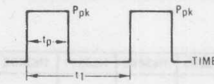


FIGURE 2 – MAXIMUM SURGE CAPABILITY



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

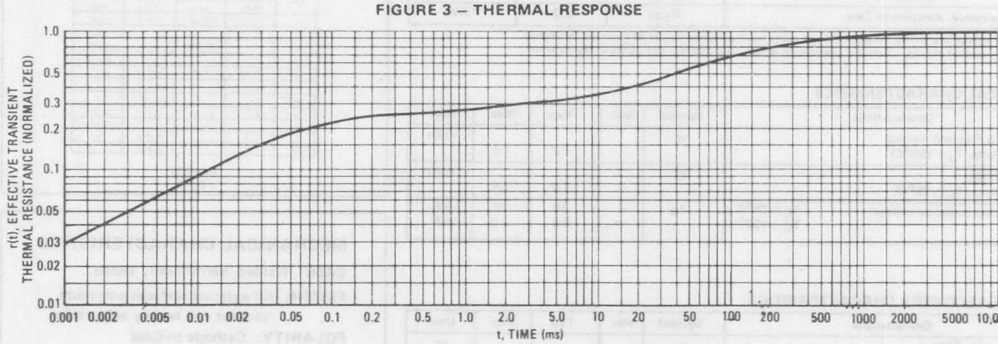
$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 3, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 3 – THERMAL RESPONSE



SINE WAVE INPUT

FIGURE 4 – FORWARD POWER DISSIPATION

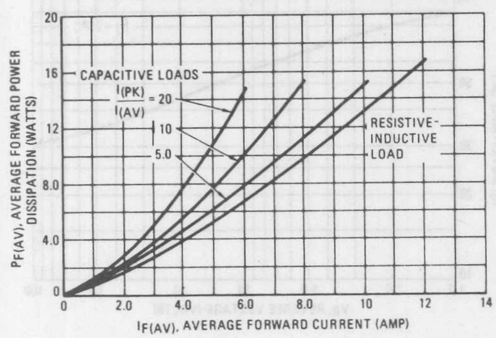


FIGURE 6 – CURRENT DERATING

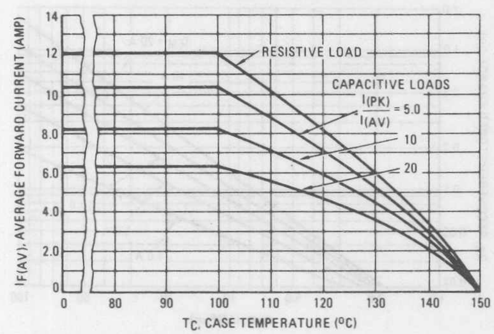
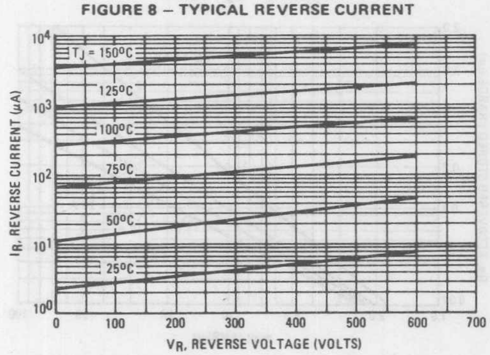


FIGURE 8 – TYPICAL REVERSE CURRENT



SQUARE WAVE INPUT

FIGURE 5 – FORWARD POWER DISSIPATION

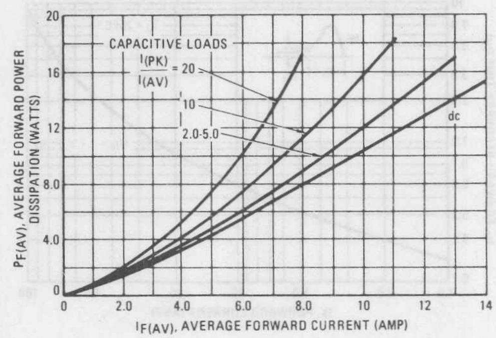


FIGURE 7 – CURRENT DERATING

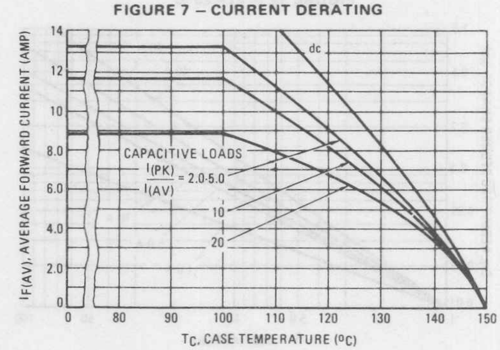
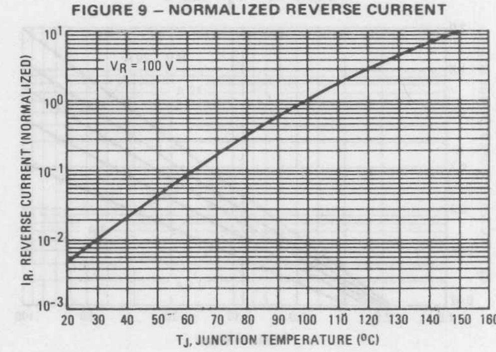


FIGURE 9 – NORMALIZED REVERSE CURRENT



TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 10 – FORWARD RECOVERY TIME

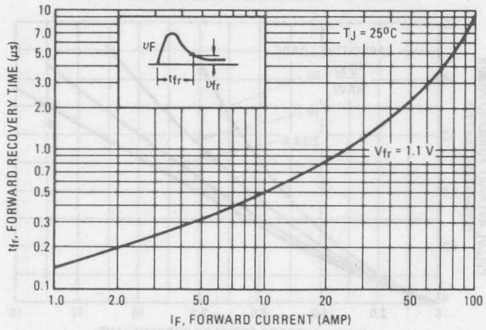
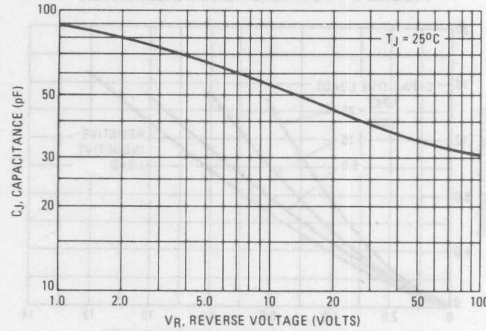


FIGURE 11 – JUNCTION CAPACITANCE



TYPICAL RECOVERED STORED CHARGE DATA

(See Note 2)

FIGURE 12 – $T_J = 25^oC$

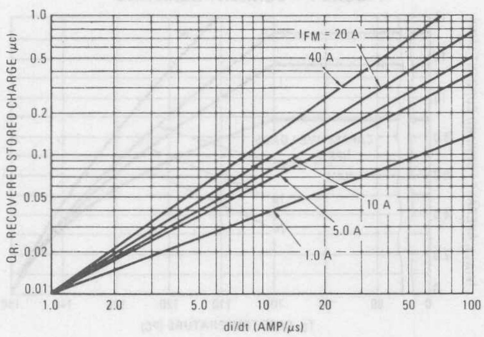


FIGURE 13 – $T_J = 75^oC$

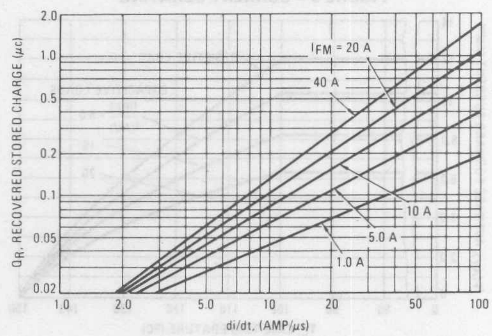


FIGURE 14 – $T_J = 100^oC$

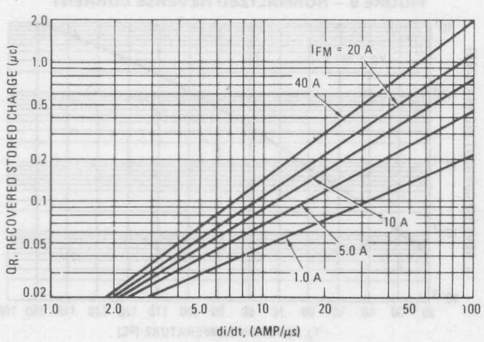


FIGURE 15 – $T_J = 150^oC$

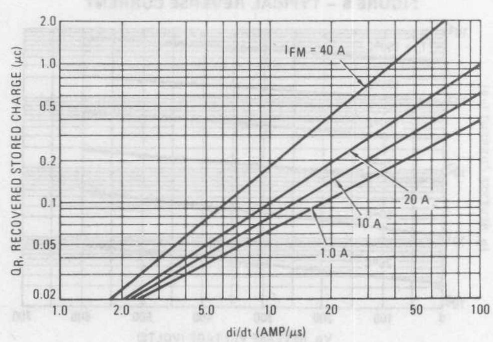
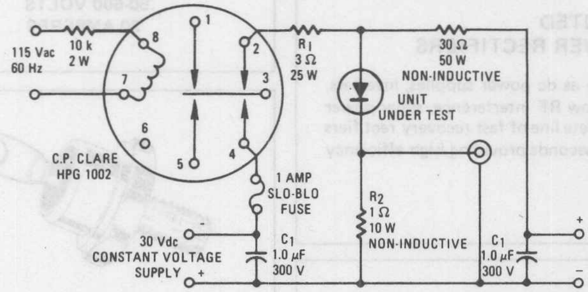


FIGURE 16 – REVERSE RECOVERY CIRCUIT



A – TEKTRONIX 545A, K PLUG IN PRE-AMP, P6000 PROBE OR EQUIVALENT

R_1 – ADJUSTED FOR 1.4 Ω BETWEEN POINT 2 OF RELAY AND RECTIFIER INDUCTANCE ≈ 38 µH

R_2 – TEN-1 W, 10 Ω, 1% CARBON CORE IN PARALLEL

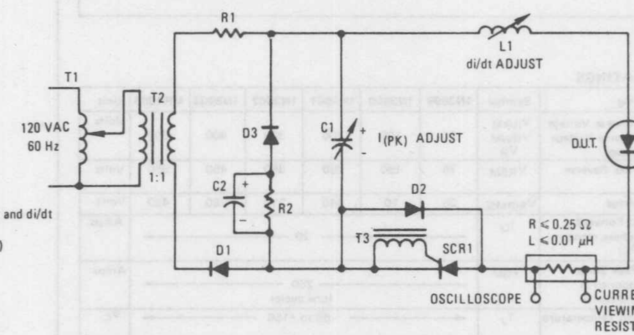
$T_A = 25\,^{+10}_{-0}\,^{\circ}C$ FOR RECTIFIER

MINIMIZE ALL LEAD LENGTHS

1.0 Adc FROM CONSTANT VOLTAGE SUPPLY
RIPPLE = 3 mVrms MAX
Z_{out} = 1½ Ω MAX, DC to 2 kHz

FIGURE 17 – JEDEC REVERSE RECOVERY CIRCUIT

R1 = 50 Ohms
R2 = 250 Ohms
D1 = 1N4723
D2 = 1N4001
D3 = 1N4933
SCR1 = MCR729-10
C1 = 0.5 to 50 µF
C2 ≈ 4000 µF
L1 = 1.0 - 27 µH
T1 = Variac Adjusts $I_{(PK)}$ and di/dt
T2 = 1:1
T3 = 1:1 (to trigger circuit)



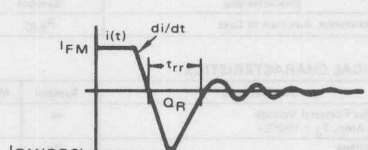
NOTE 2

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

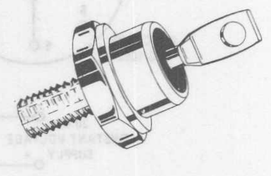
MOTOROLA

1N3899 thru 1N3903
MR1386

Designers Data Sheet

FAST RECOVERY
POWER RECTIFIERS

50-600 VOLTS
20 AMPERES

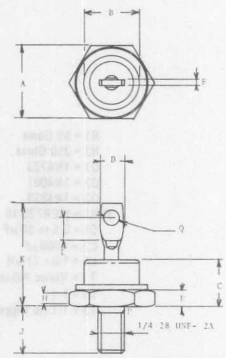


STUD MOUNTED
FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference, sonar power supplies and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

Designers Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.



DIM	MILLIMETERS		INCHES	
	min.	max	min	max
A	16.94	17.45	0.667	0.687
B	-	16.94	-	0.667
C	-	11.43	-	0.450
D	-	9.53	-	0.375
E	2.92	5.08	0.115	0.200
F	-	2.03	-	0.080
H	1.52	-	0.060	-
J	10.72	11.51	0.422	0.453
K	-	25.40	-	1.000
L	3.86	-	0.152	-
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

CASE 257
DO-5

*MAXIMUM RATINGS

Rating	Symbol	1N3899	1N3900	1N3901	1N3902	1N3903	MR1386	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	350	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^oC$)	I_O	20						Amps
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	250 (one cycle)						Amps
Operating Junction Temperature Range	T_J	-65 to +150						^oC
Storage Temperature Range	T_{stg}	-65 to +175						^oC

*THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.8	$^oC/W$

*ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (i_F = 63 Amp, $T_J = 150^oC$)	v_F	–	1.2	1.5	Volts
Forward Voltage (I_F = 20 Amp, $T_C = 25^oC$)	V_F	–	1.1	1.4	Volts
Reverse Current (rated dc voltage) $T_C = 25^oC$ $T_C = 100^oC$	I_R	–	10 0.5	50 6.0	μA mA

*REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16) (I_{FM} = 36 Amp, di/dt = 25 A/μs, Figure 17)	t_{rr}	– –	150 200	200 400	ns
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16)	$I_{RM(REC)}$	–	–	3.0	Amp

*Indicates JEDEC Registered Data for 1N3899 Series.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and readily solderable

POLARITY: Cathode to Case

WEIGHT: 17 Grams (Approximately)

MOUNTING TORQUE: 25 in-lbs max.

FIGURE 1 – FORWARD VOLTAGE

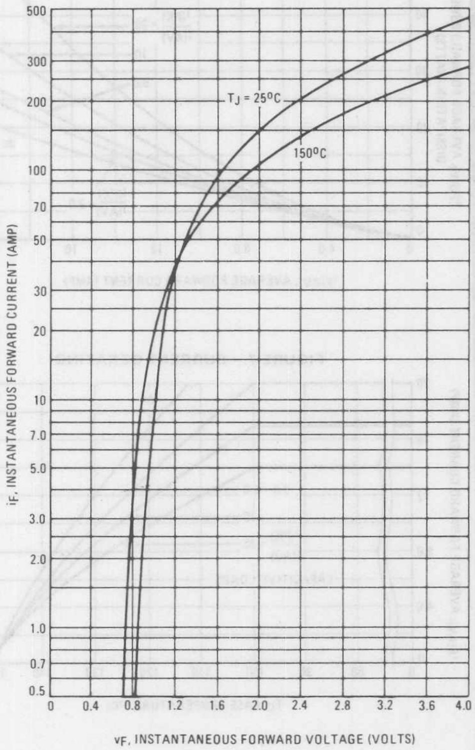
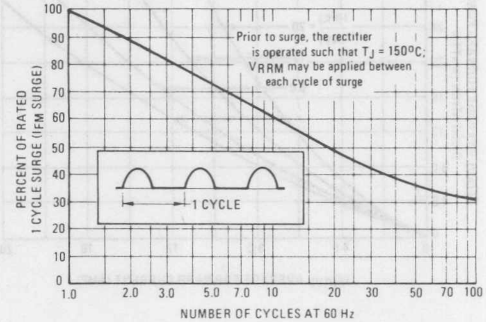
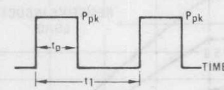


FIGURE 2 – MAXIMUM SURGE CAPABILITY



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

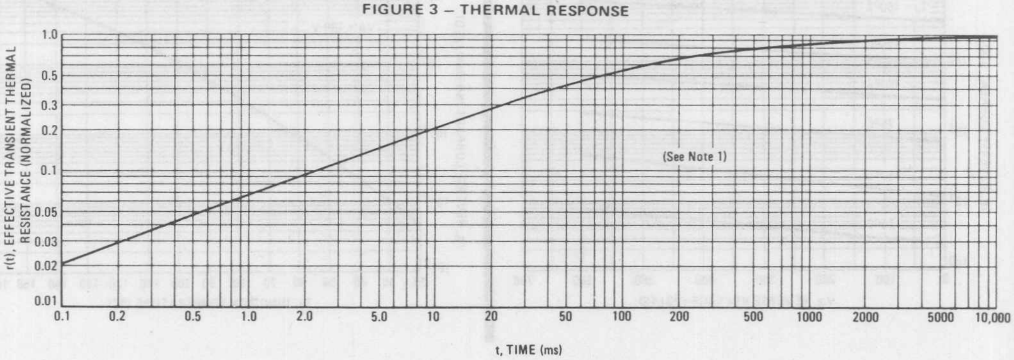
$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 3, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

FIGURE 3 – THERMAL RESPONSE



SINE WAVE INPUT

FIGURE 4 – FORWARD POWER DISSIPATION

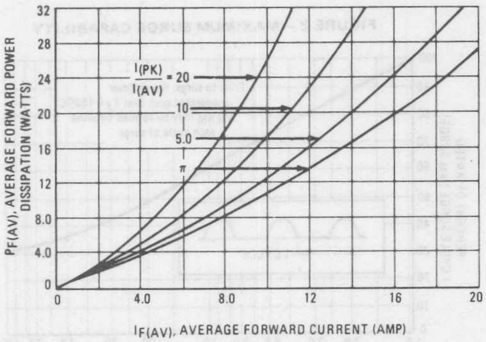


FIGURE 6 – CURRENT DERATING

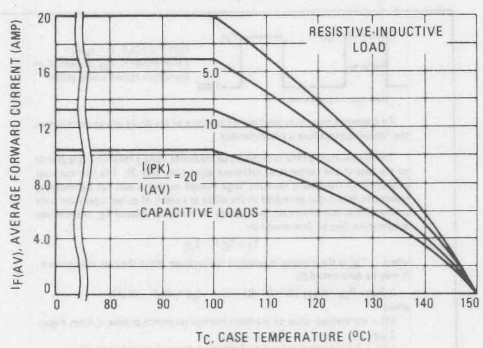
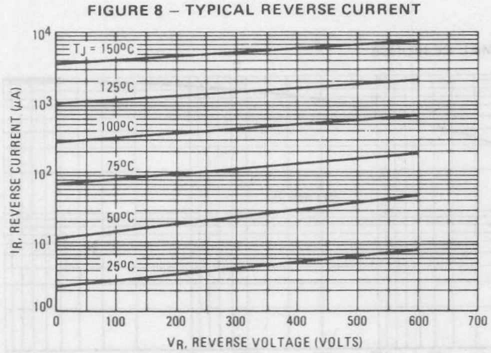


FIGURE 8 – TYPICAL REVERSE CURRENT



SQUARE WAVE INPUT

FIGURE 5 – FORWARD POWER DISSIPATION

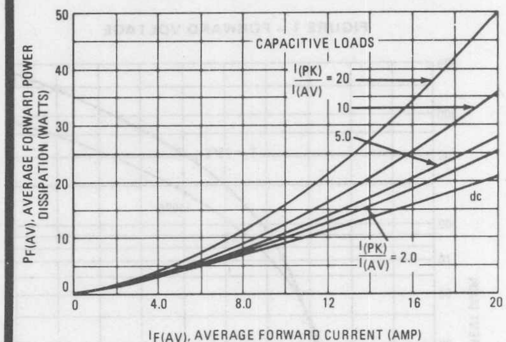


FIGURE 7 – CURRENT DERATING

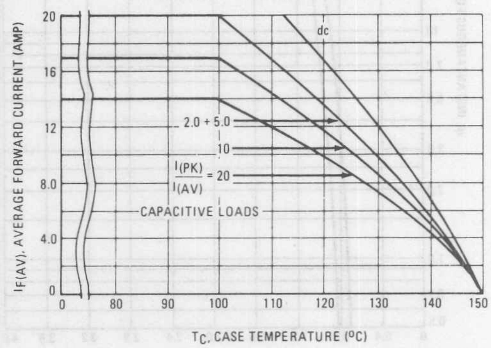
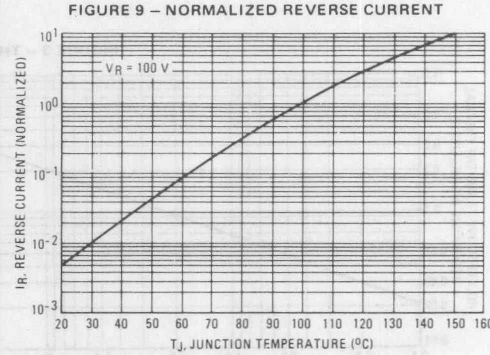


FIGURE 9 – NORMALIZED REVERSE CURRENT



TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 10 – FORWARD RECOVERY TIME

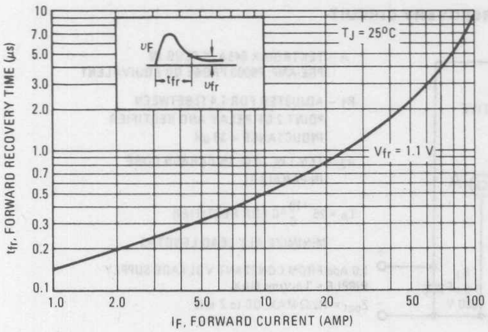
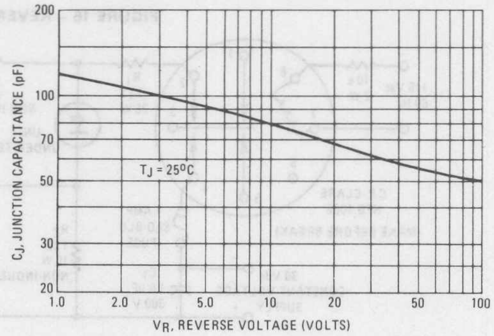


FIGURE 11 – JUNCTION CAPACITANCE



TYPICAL RECOVERED STORED CHARGE DATA

(See Note 2)

FIGURE 12 – $T_J = 25^oC$

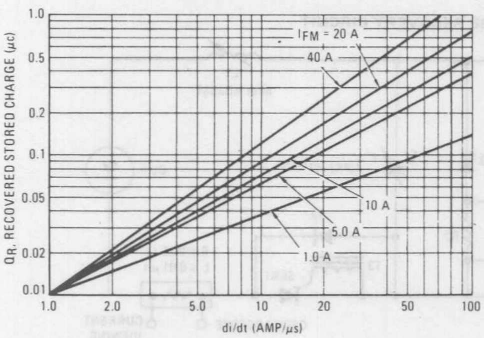
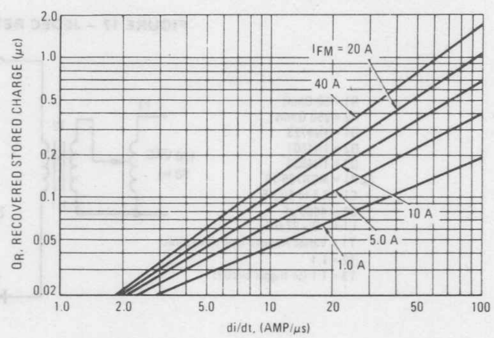


FIGURE 13 – $T_J = 75^oC$



STORED CHARGE DATA

FIGURE 14 – $T_J = 100^oC$

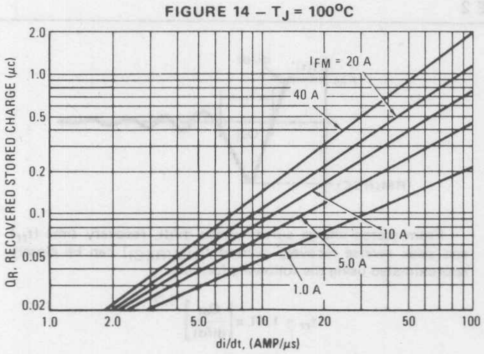


FIGURE 15 – $T_J = 150^oC$

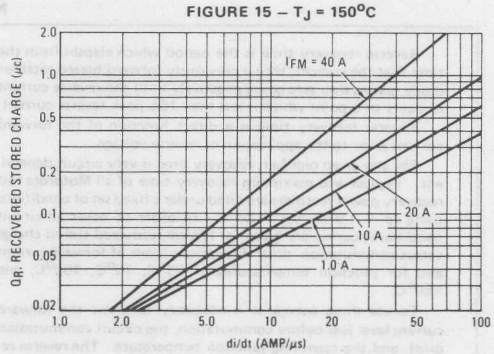


FIGURE 16 – REVERSE RECOVERY CIRCUIT

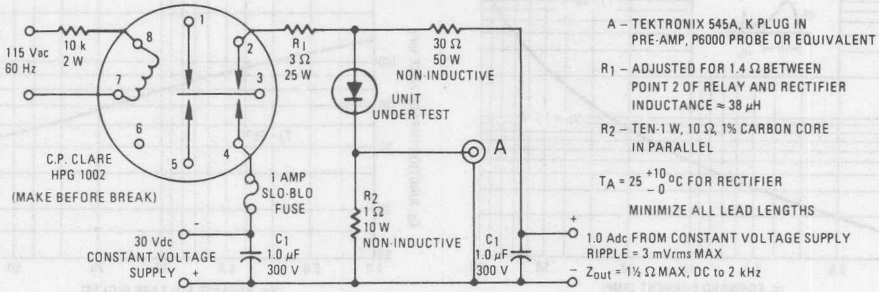
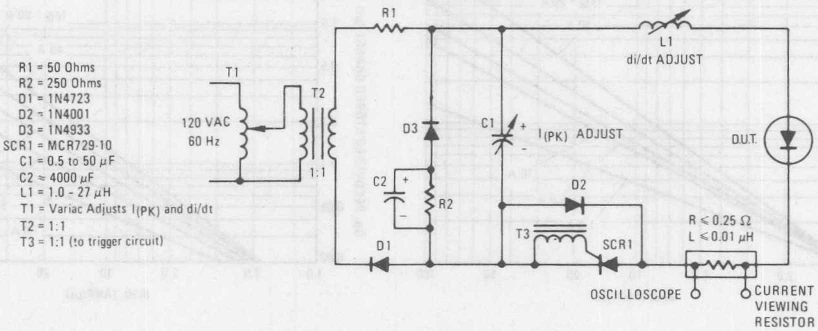


FIGURE 17 – JEDEC REVERSE RECOVERY CIRCUIT



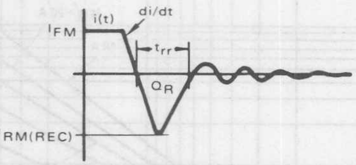
NOTE 2

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

MOTOROLA

1N3909 thru 1N3913
MR1396

Designers Data Sheet

STUD MOUNTED
FAST RECOVERY POWER RECTIFIERS

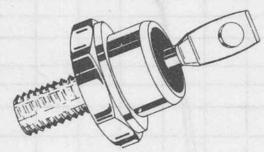
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference, sonar power supplies and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

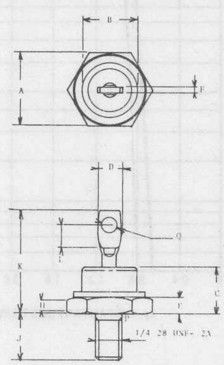
Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics -- are given to facilitate "worst case" design.

FAST RECOVERY POWER RECTIFIERS

50-600 VOLTS
30 AMPERES





DIM	MILLIMETERS		INCHES	
	min.	max	min	max
A	16.94	17.45	0.667	0.687
B	-	16.94	-	0.667
C	-	11.43	-	0.450
D	-	9.53	-	0.375
E	2.92	5.08	0.115	0.200
F	-	2.03	-	0.080
H	1.52	-	0.060	-
J	10.72	11.51	0.422	0.453
K	-	25.40	-	1.000
L	3.86	-	0.152	-
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

CASE 257
DO-5

*MAXIMUM RATINGS

Rating	Symbol	1N3909	1N3910	1N3911	1N3912	1N3913	MR1396	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	350	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^oC$)	I_O	← 30 →						Amps
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	← 300 →						Amp
Operating Junction Temperature Range	T_J	← -65 to +150 →						^oC
Storage Temperature Range	T_{stg}	← -65 to +175 →						^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.2	$^oC/W$

*ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (i_F = 93 Amp, $T_J = 150^oC$)	v_F	–	1.2	1.5	Volts
Forward Voltage (I_F = 30 Amp, $T_C = 25^oC$)	V_F	–	1.1	1.4	Volts
Reverse Current (rated dc voltage) $T_C = 25^oC$ $T_C = 100^oC$	I_R	– –	10 0.5	25 1.0	μA mA

*REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16) (I_{FM} = 36 Amp, di/dt = 25 A/μs, Figure 17)	t_{rr}	 – –	 150 200	 200 400	ns
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16)	$I_{RM(REC)}$	–	1.5	2.0	Amp

*Indicates JEDEC Registered Data for 1N3909 Series.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and readily solderable

POLARITY: Cathode to Case

WEIGHT: 17 Grams (Approximately)

MOUNTING TORQUE: 25 in-lbs max.

FIGURE 1 – FORWARD VOLTAGE

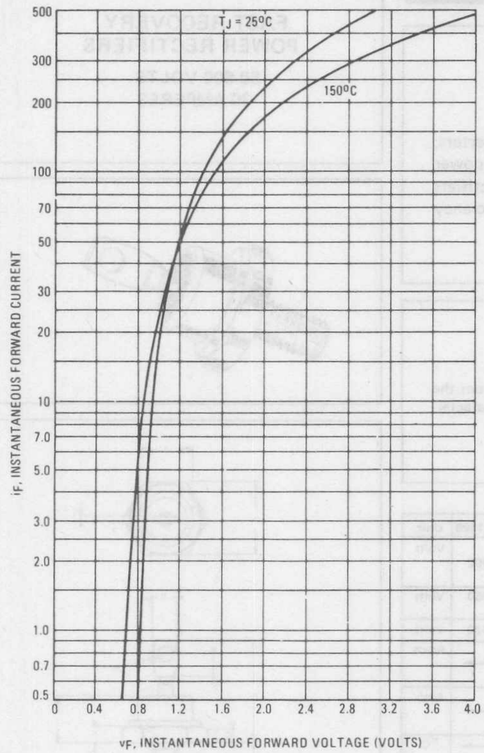
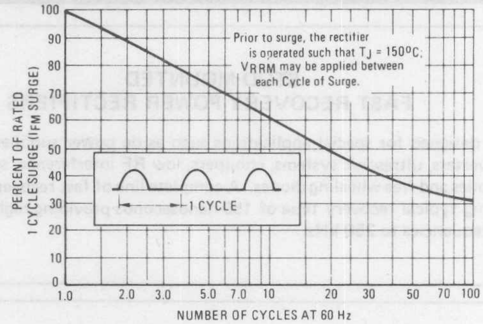
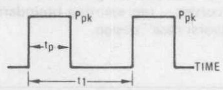


FIGURE 2 – MAXIMUM SURGE CAPABILITY



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

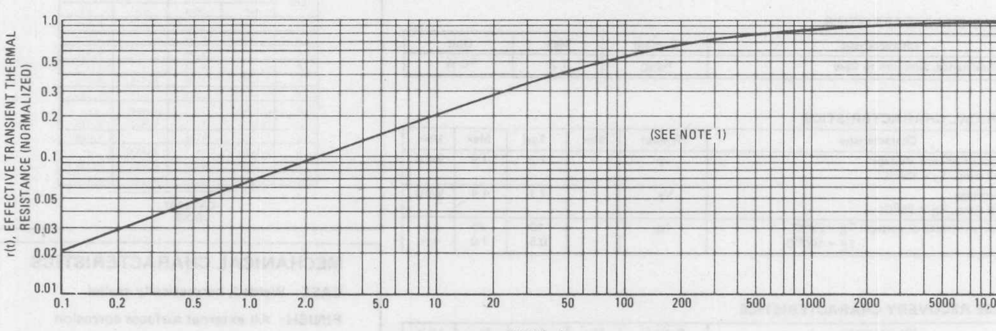
$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)\right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 3, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 3 – THERMAL RESPONSE



SINE WAVE INPUT

FIGURE 4 – FORWARD POWER DISSIPATION

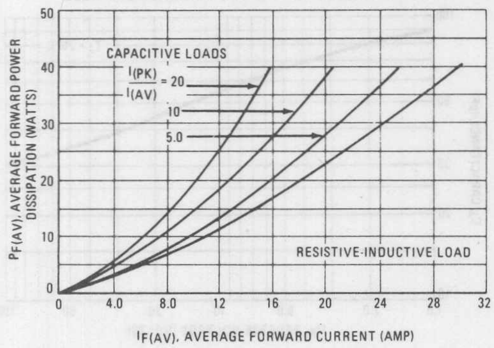


FIGURE 6 – CURRENT DERATING

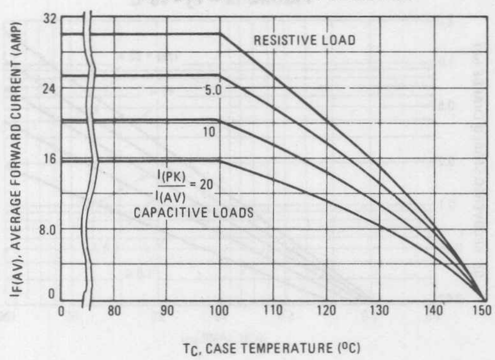
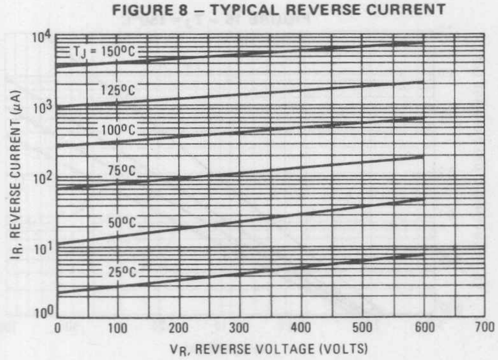


FIGURE 8 – TYPICAL REVERSE CURRENT



SQUARE WAVE INPUT

FIGURE 5 – FORWARD POWER DISSIPATION

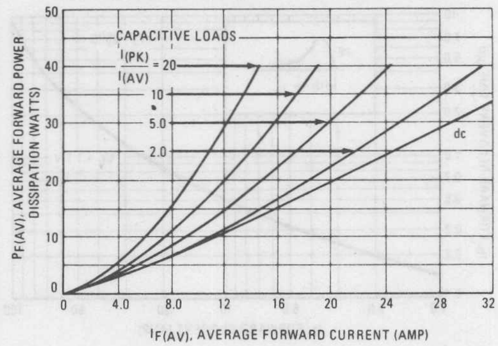


FIGURE 7 – CURRENT DERATING

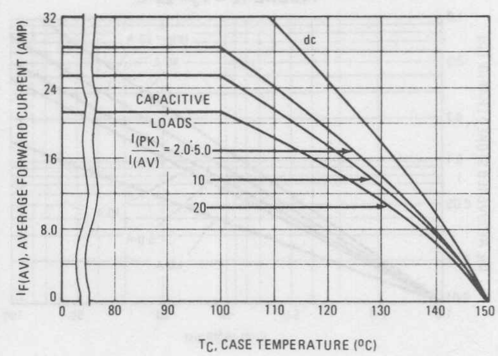
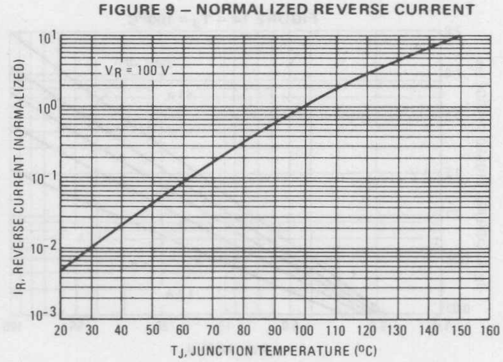


FIGURE 9 – NORMALIZED REVERSE CURRENT



TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 10 – FORWARD RECOVERY TIME

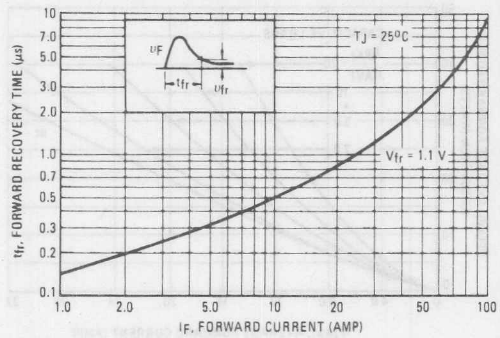
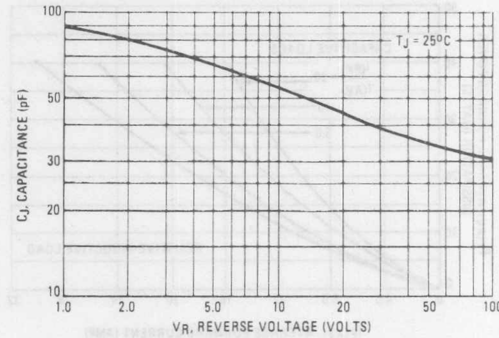


FIGURE 11 – JUNCTION CAPACITANCE



TYPICAL RECOVERED STORED CHARGE DATA

(See Note 2)

FIGURE 12 – $T_J = 25^oC$

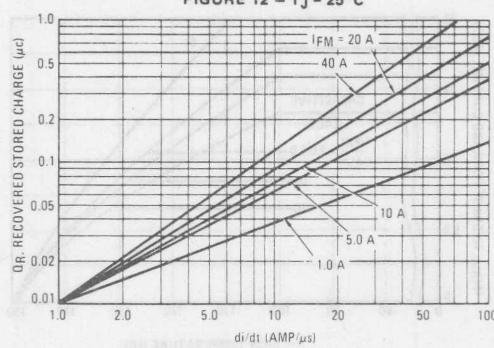


FIGURE 13 – $T_J = 75^oC$

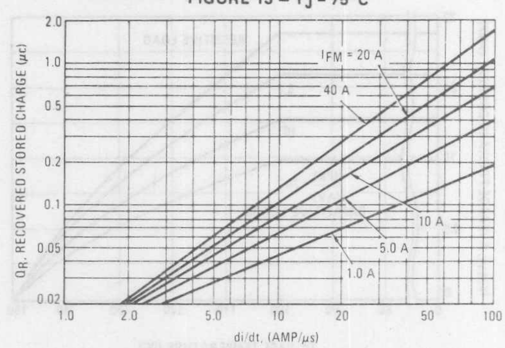


FIGURE 14 – $T_J = 100^oC$

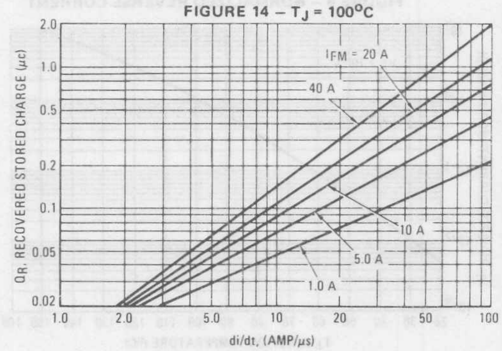


FIGURE 15 – $T_J = 150^oC$

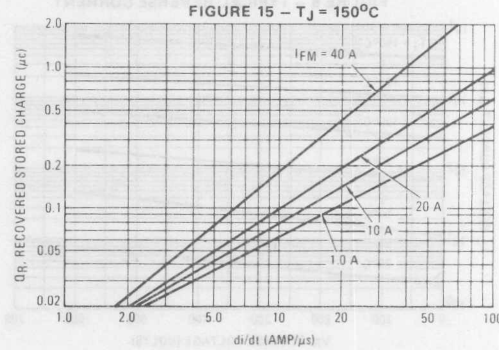
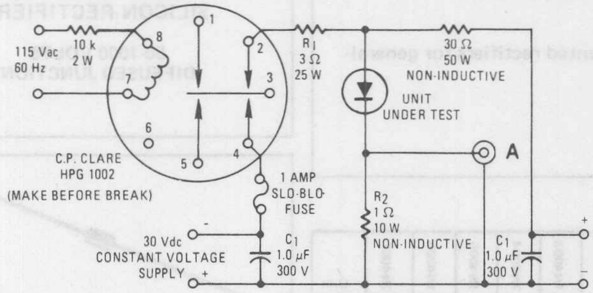


FIGURE 16 – REVERSE RECOVERY CIRCUIT



A – TEKTRONIX 545A, K PLUG IN PRE-AMP, P6000 PROBE OR EQUIVALENT

R_1 – ADJUSTED FOR 1.4 Ω BETWEEN POINT 2 OF RELAY AND RECTIFIER INDUCTANCE ≈ 38 µH

R_2 – TEN-1 W, 10 Ω, 1% CARBON CORE IN PARALLEL

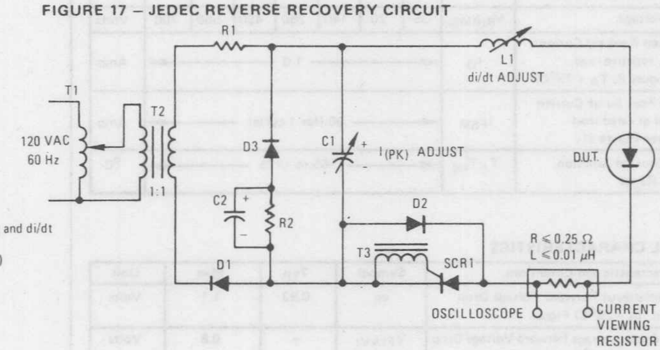
$T_A = 25\,^{+10}_{-0}\,^{\circ}C$ FOR RECTIFIER

MINIMIZE ALL LEAD LENGTHS

1.0 Adc FROM CONSTANT VOLTAGE SUPPLY
RIPPLE = 3 mVrms MAX
Z_{out} = 1½ Ω MAX, DC to 2 kHz

FIGURE 17 – JEDEC REVERSE RECOVERY CIRCUIT

R1 = 50 Ohms
R2 = 250 Ohms
D1 = 1N4723
D2 = 1N4001
D3 = 1N4933
SCR1 = MCR729-10
C1 = 0.5 to 50 µF
C2 ≈ 4000 µF
L1 = 1.0 - 27 µH
T1 = Variac Adjusts $I_{(PK)}$ and di/dt
T2 = 1:1
T3 = 1:1 (to trigger circuit)



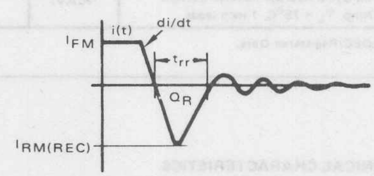
NOTE 2

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

MOTOROLA

1N4001, S thru 1N4007, S

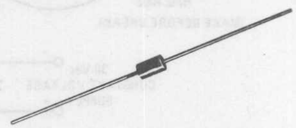
GENERAL-PURPOSE RECTIFIERS

. . . subminiature size, axial lead mounted rectifiers for general-purpose low-power applications.

1N4001S version has square dice

LEAD MOUNTED SILICON RECTIFIERS

50-1000 VOLTS DIFFUSED JUNCTION



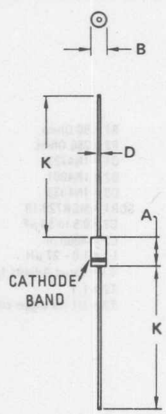
*MAXIMUM RATINGS

Rating	Symbol	1N4001	1N4002	1N4003	1N4004	1N4005	1N4006	1N4007	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz, see Figure 8, $T_A = 75°C$)	I_O	← 1.0 →							Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions, see Figure 2)	I_{FSM}	← 30 (for 1 cycle) →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -65 to +175 →							°C

*ELECTRICAL CHARACTERISTICS

Characteristic and Conditions	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop ($i_F = 1.0$ Amp, $T_J = 25°C$) Figure 1	v_F	0.93	1.1	Volts
Maximum Full-Cycle Average Forward Voltage Drop ($I_O = 1.0$ Amp, $T_L = 75°C$, 1 inch leads)	$V_{F(AV)}$	–	0.8	Volts
Maximum Reverse Current (rated dc voltage) $T_J = 25°C$	I_R	0.05	10	µA
$T_J = 100°C$		1.0	50	
Maximum Full-Cycle Average Reverse Current ($I_O = 1.0$ Amp, $T_L = 75°C$, 1 inch leads)	$I_{R(AV)}$	–	30	µA

*Indicates JEDEC Registered Data.



	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	24.70	5.20	0.185	0.205
B	2.79	3.05	0.110	0.120
D				0.034
K	25.4		1.000	

DOES NOT CONFORM TO JEDEC DO-41 OUTLINE 1N4001S SERIES

Case 59 - 4

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

1N4001 SERIES

MECHANICAL CHARACTERISTICS

CASE: Void free, Transfer Molded

MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 350°C, 3/8" from case for 10 seconds at 5 lbs. tension

FINISH: All external surfaces are corrosion-resistant, leads are readily solderable

POLARITY: Cathode indicated by color band

WEIGHT: 0.40 Grams (approximately)

![MOTOROLA]

MOTOROLA

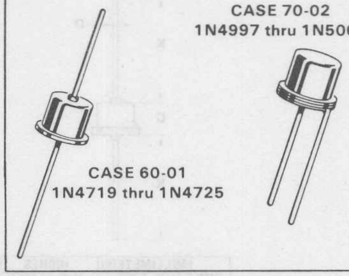
1N4719 thru 1N4725
1N4997 thru 1N5003

LEAD MOUNTED POWER RECTIFIERS

. . . having low forward voltage drop and hermetic metal packages. High surge current capability and good thermal characteristics provide reliable operation.

SILICON RECTIFIERS

3.0 AMPERES
50-1000 VOLTS
DIFFUSED JUNCTION



CASE 70-02
1N4997 thru 1N5003

CASE 60-01
1N4719 thru 1N4725

***MAXIMUM RATINGS** (Both Package Types) $T_A = 25°C$ unless otherwise noted.

Rating	Symbol	1N4719 1N4997	1N4720 1N4998	1N4721 1N4999	1N4722 1N5000	1N4723 1N5001	1N4724 1N5002	1N4725 1N5003	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Nonrepetitive Peak Reverse Voltage (one half-wave, single phase, 60 cycle peak)	V_{RSM}	100	200	300	500	720	1000	1200	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz, $T_A = 75°C$)	I_O	← 3.0 →							Amp
Nonrepetitive Peak Surge Current (superimposed on rated current at rated voltage, $T_A = 75°C$)	I_{FSM}	← 300 (for 1/2 cycle) →							Amp
Operating and Case Temperature	T_J, T_{stg}	← −65 to +175 →							°C

ELECTRICAL CHARACTERISTICS

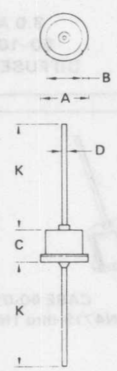
Characteristic	Symbol	Max Limit	Unit
*Instantaneous Forward Voltage ($i_F = 3.0$ A, $T_J = 75°C$, Half Wave Rectifier)	v_F	1.0	Volts
*Full Cycle Average Reverse Current ($I_O = 3.0$ Amps and Rated V_R, $T_A = 75°C$, Half Wave Rectifier)	$I_{R(AV)}$	1.5	mA
DC Reverse Current (Rated V_R, $T_A = 25°C$)	I_R	0.5	mA

*Indicates JEDEC Registered Data.

MECHANICAL CHARACTERISTICS

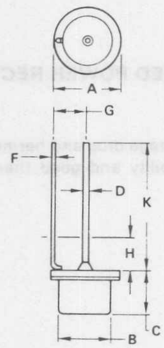
CASE: Welded, hermetically sealed construction
FINISH: All external surfaces corrosion-resistant and leads readily solderable.
POLARITY: CATHODE TO CASE (reverse polarity units are available upon request and are designated by an "R" suffix i.e. 1N4720R).
MOUNTING POSITIONS: Any.

OUTLINE DIMENSIONS



DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	–	11.43	–	0.450
B	–	8.89	–	0.350
C	–	7.62	–	0.300
D	1.17	1.42	0.046	0.056
K	24.89	–	0.980	–

CASE 60-1



NOTE:
1. DIM "G" CONTROLLED WITHIN ZONE "H".

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	10.16	12.70	0.400	0.500
B	7.62	8.89	0.300	0.350
C	6.60	8.89	0.260	0.350
D	1.17	1.42	0.046	0.056
F	0.69	0.94	0.027	0.037
G	4.19	4.95	0.165	0.195
H	3.05	3.30	0.120	0.130
K	22.86	–	0.900	–

CASE 70-02

MOTOROLA

1N4933 thru 1N4937

Designers Data Sheet

AXIAL-LEAD, FAST-RECOVERY RECTIFIERS

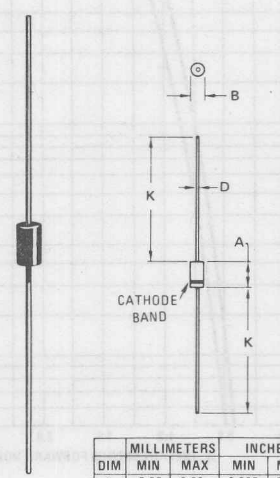
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

FAST RECOVERY RECTIFIERS

50–600 VOLTS
1 AMPERE

Designer's Data for "Worst Case" Conditions

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves — representing device characteristics boundaries — are given to facilitate "worst case" design.



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

CASE 59-04
(Does not meet DO-41 outline)

***MAXIMUM RATINGS**

Rating	Symbol	1N4933	1N4934	1N4935	1N4936	1N4937	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	Volts
Nonrepetitive Peak Reverse Voltage RMS Reverse Voltage	V_{RSM} $V_{R(RMS)}$	75 35	150 70	250 140	450 280	650 420	Volts Volts
Average Rectified Forward Current (Single phase, resistive load, $T_A = 75°C$)	I_O	←	—	1.0	—	→	Amp
Nonrepetitive Peak Surge Current (Surge applied at rated load conditions)	I_{FSM}	←	—	30	—	→	Amps
Operating Junction Temperature Range Storage Temperature Range	T_J T_{stg}	←	—	-65 to +150 -65 to +175	—	→	°C °C

***THERMAL CHARACTERISTICS**

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Typical Printed Circuit-Board Mounting)	$R_{\theta JC}$	65	°C/W

***ELECTRICAL CHARACTERISTICS**

Characteristic	Symbol	Min	Typ	Max	Unit
*Instantaneous Forward Voltage (i_F = 3.14 Amp, T_J = 150°C)	v_F	–	1.0	1.2	Volts
Forward Voltage (I_F = 1.0 Amp, T_A = 25°C)	V_F	–	1.0	1.1	Volts
*Reverse Current (Rated dc Voltage) T_A = 25°C T_A = 100°C	I_R	– –	1.0 50	5.0 100	μA

***REVERSE RECOVERY CHARACTERISTICS**

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time (I_F = 1.0 Amp to V_R = 30 Vdc) (Figure 21) (I_{FM} = 15 Amp, di/dt = 10A/μs (Figure 22)	t_{rr}	– –	150 175	200 300	ns
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc) (Figure 21)	$I_{RM(REC)}$	–	1.0	2.0	Amp

*Indicates JEDEC Registered Data

MECHANICAL CHARACTERISTICS

CASE: Void free, transfer molded
FINISH: External leads are readily solderable
POLARITY: Cathode indicated by polarity band
WEIGHT: 0.4 Gram (approximately)

FIGURE 1 – FORWARD VOLTAGE

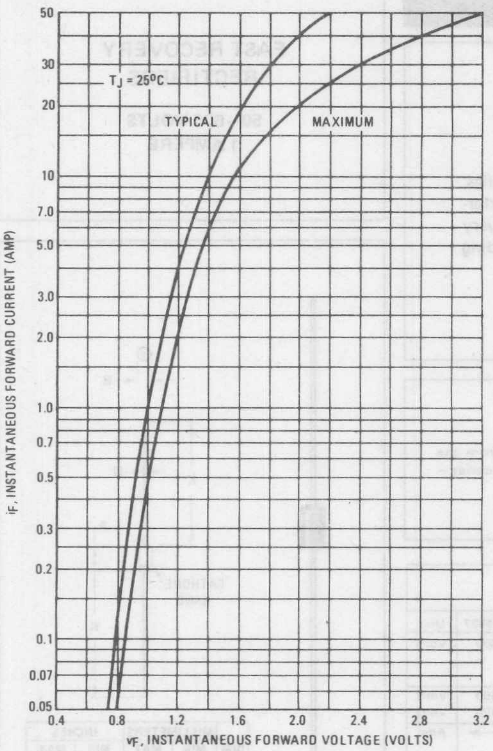


FIGURE 2 – MAXIMUM SURGE CAPABILITY

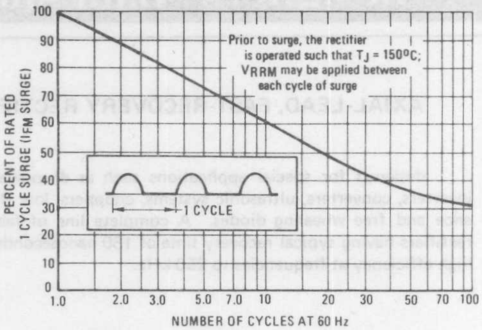
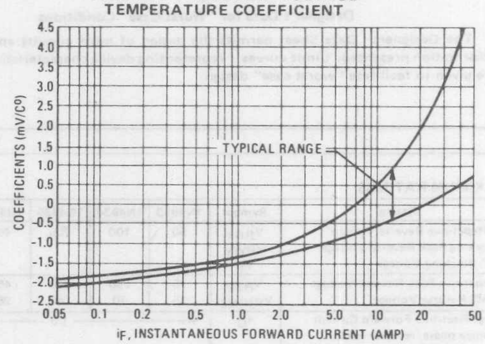
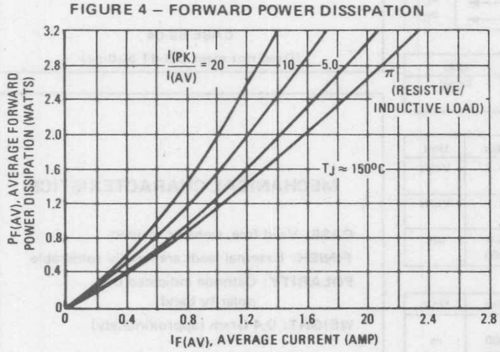


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT



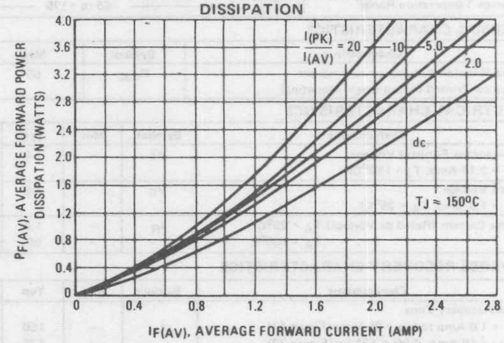
SINE WAVE INPUT

FIGURE 4 – FORWARD POWER DISSIPATION



SQUARE WAVE INPUT

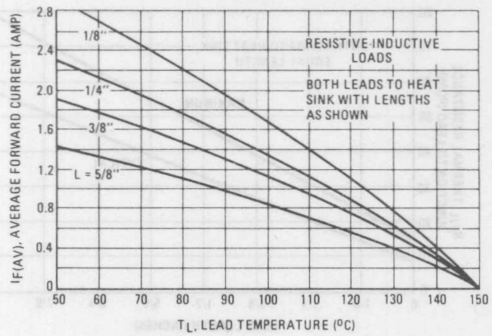
FIGURE 5 – FORWARD POWER DISSIPATION



MAXIMUM CURRENT RATINGS

SINE WAVE INPUT

FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD



SQUARE WAVE INPUT

FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

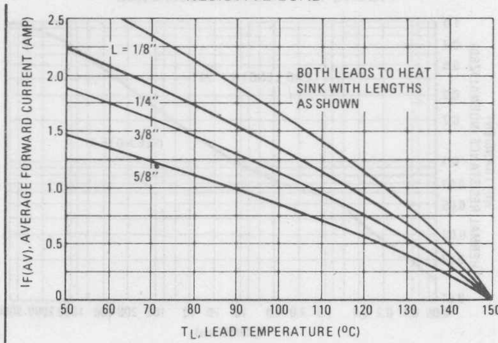


FIGURE 8 – 1/8" LEAD LENGTH, VARIOUS LOADS

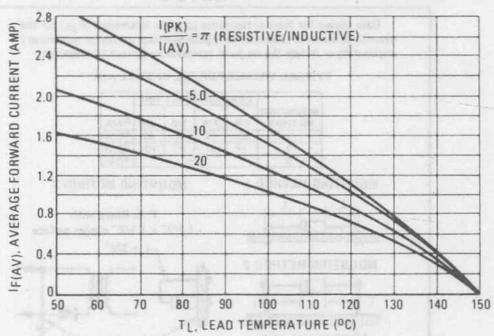


FIGURE 9 – 1/8" LEAD LENGTHS, VARIOUS LOADS

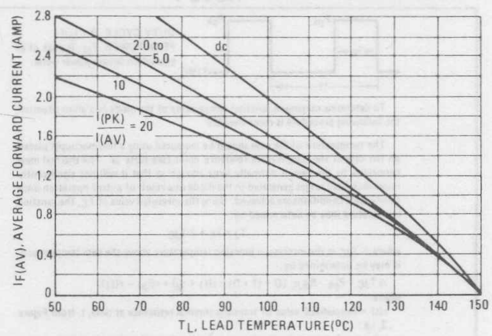


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

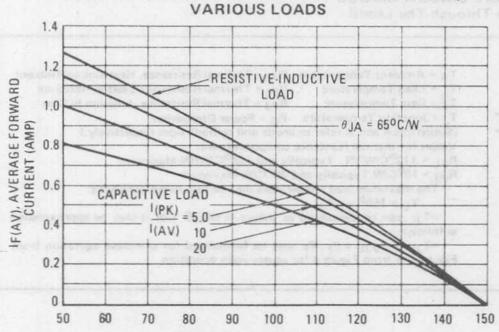


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

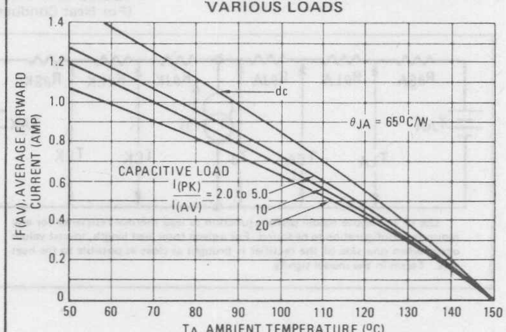


FIGURE 12 – THERMAL RESPONSE

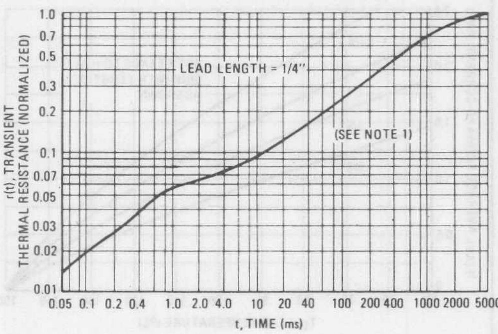
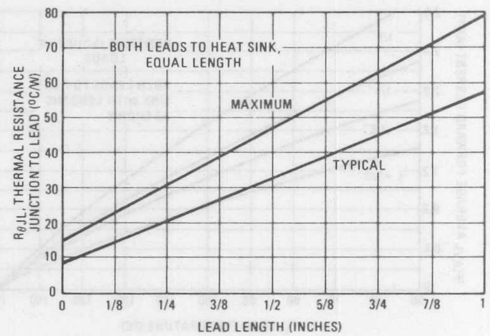
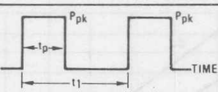


FIGURE 13 – THERMAL RESISTANCE



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)\right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 3, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

NOTE 2

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN) 1/8	1/4	1/2	3/4	$R_{\theta JA}$
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W

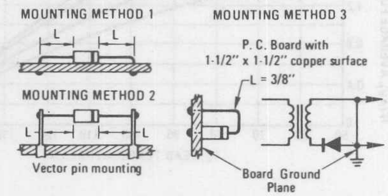
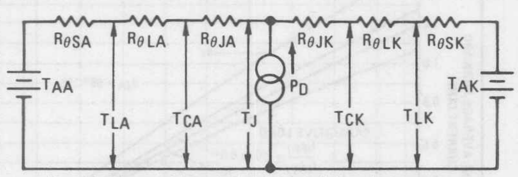


FIGURE 14 – THERMAL CIRCUIT MODEL
(For Heat Conduction Through The Leads)



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Power Dissipation
(Subscripts A and K refer to anode and cathode sides respectively.)

Values for thermal resistance components are:
$R_{\theta L}$ = 112°C/W/iN. Typically and 128°C/W/IN Maximum
$R_{\theta J}$ = 18°C/W Typically and 30°C/W Maximum

The maximum lead temperature may be calculated as follows:

$$T_L = 150^{o} - \Delta T_{JL}$$

ΔT_{JL} can be calculated as shown in NOTE 1 or it may be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \bullet P_F$; P_F may be formulated for sine-wave operation from Figure 3 or from Figure 4 for square-wave operation.

TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 15 – FORWARD RECOVERY TIME

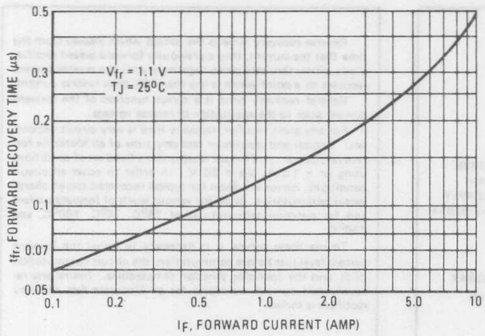
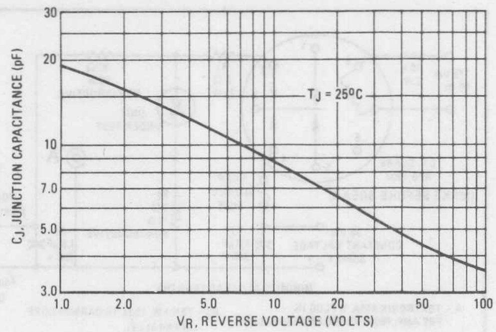


FIGURE 16 – JUNCTION CAPACITANCE



TYPICAL RECOVERED STORED CHARGED DATA

FIGURE 17 – T_J = 25°C

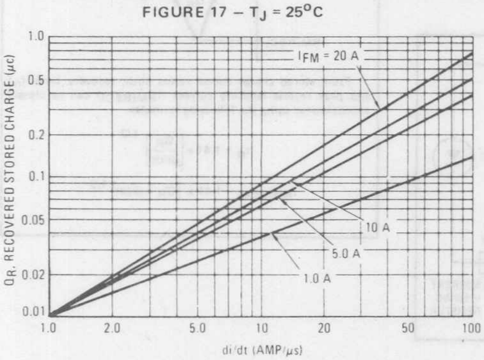


FIGURE 18 – T_J = 75°C

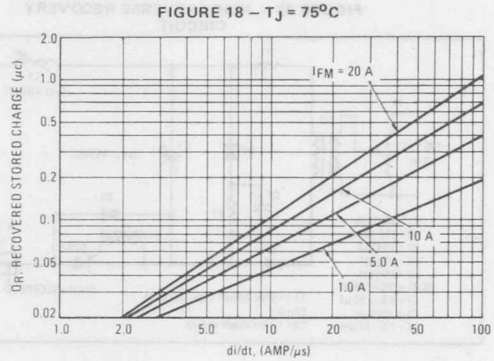


FIGURE 19 – T_J = 100°C

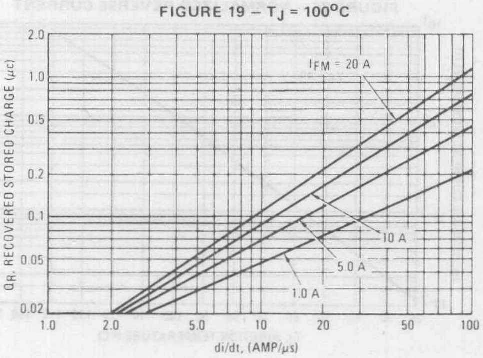
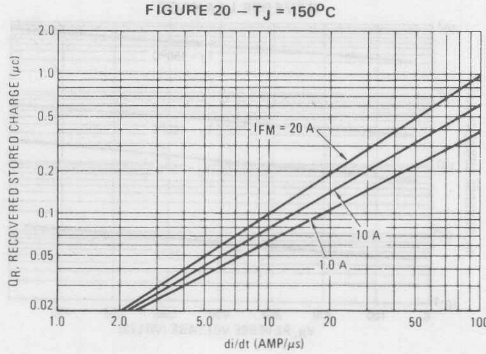


FIGURE 20 – T_J = 150°C



RECOVERY TIME

FIGURE 21 – REVERSE RECOVERY CIRCUIT

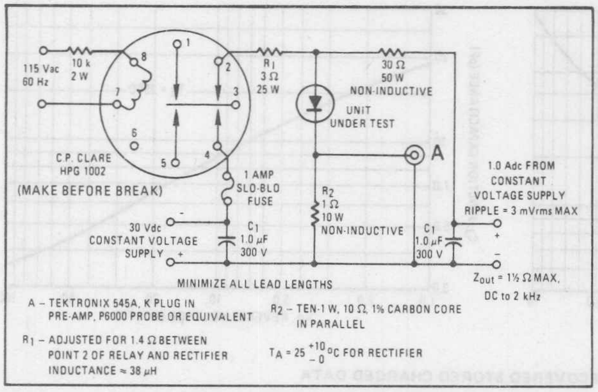
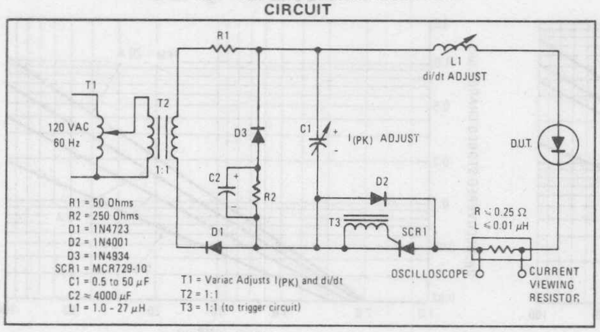


FIGURE 22 – JEDEC REVERSE RECOVERY CIRCUIT



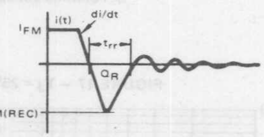
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

FIGURE 23 – TYPICAL REVERSE LEAKAGE

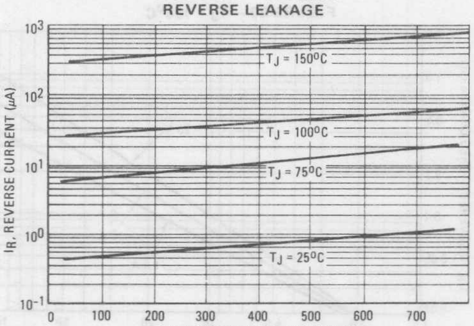
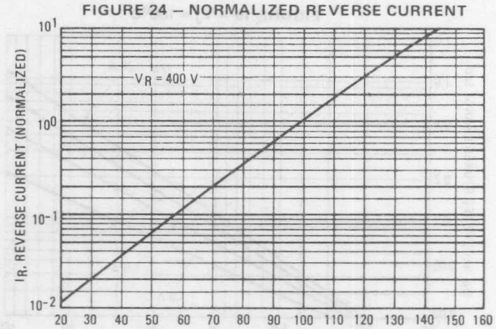


FIGURE 24 – NORMALIZED REVERSE CURRENT



MOTOROLA

1N5400 thru 1N5408

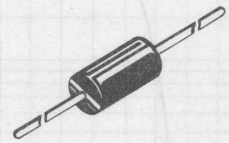
STANDARD RECOVERY RECTIFIERS

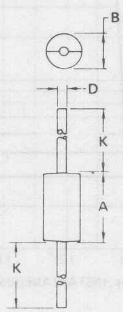
50–1000 VOLTS
3 AMPERES

LEAD MOUNTED STANDARD RECOVERY RECTIFIERS

. . . designed for use in power supplies and other applications having need of a device with the following features:

- High Current to Small Size
- High Surge Current Capability
- Low Forward Voltage Drop
- Void-Free Economical Plastic Package
- Available in Volume Quantities





DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	9.65	0.370	0.380
B	4.83	5.33	0.190	0.210
D	1.22	1.32	0.048	0.052
K	26.97	27.23	1.062	1.072

CASE 267-01

MAXIMUM RATINGS

Rating	Symbol	1N5400	1N5401	1N5402	1N5404	1N5406	1N5407	1N5408	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Nonrepetitive Peak Reverse Voltage	V_{RSM}	100	200	300	525	800	1000	1200	Volts
Average Rectified Foward Current (Single Phase Resistive Load, (1/2″ Leads, T_L = 105°C)	I_O	← 3.0 →							Amp
Nonrepetitive Peak Surge Current (Surge Applied at Rated Load Conditions)	I_{FSM}	← 200 (one cycle) →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← –65 to +175 →							°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Typ	Unit
Thermal Resistance, Junction to Ambient (PC Board Mount, 1/2″ Leads)	$R_{\theta JA}$	53	°C/W

*ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (1) (i_F = 9.4 Amp)	v_F	–	–	1.2	Volts
Average Reverse Current (1) DC Reverse Current (Rated dc Voltage, T_L = 150°C)	$I_{R(AV)}$ I_R	– –	– –	500 500	μA

*JEDEC Registered Data.

(1) Measured in a single-phase half-wave circuit such as shown in Figure 6.25 of EIA RS-282, November 1963. Operated at rated load conditions T_L=105°C, I_O=3.0 A, V_r=V_{RWM}.

MECHANICAL CHARACTERISTICS

Case: Void Free, Transfer Molded
Finish: External Leads are Plated, Leads are readily Solderable
Polarity: Indicated by Cathode Band
Weight: 1.1 Grams (Approximately)
Maximum Lead Temperature for Soldering Purposes:
240°C, 1/8″ from case for 10 s at 5.0 lb. tension

FIGURE 1 – FORWARD VOLTAGE

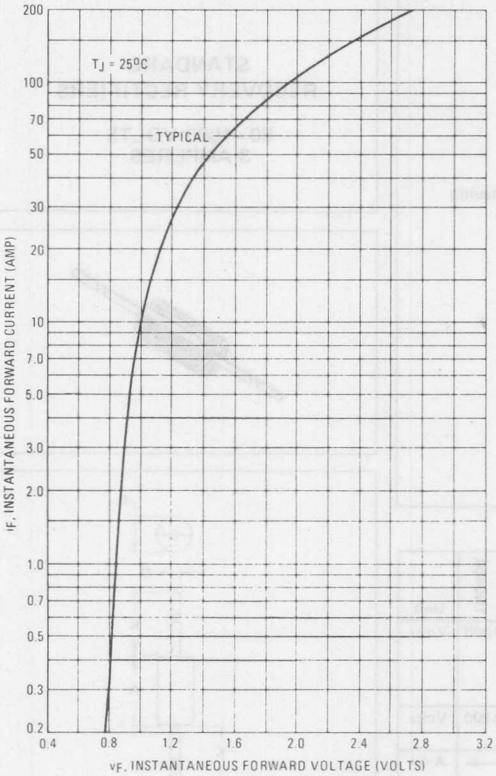


FIGURE 2 – MAXIMUM NONREPETITIVE SURGE CURRENT

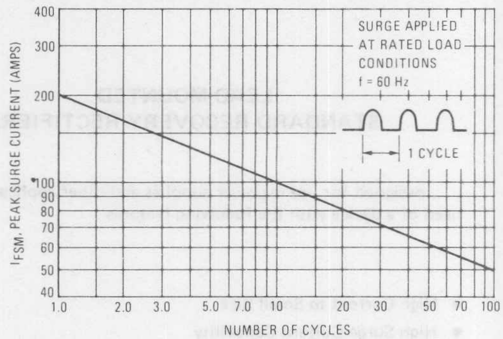


FIGURE 3 – CURRENT DERATING VARIOUS LEAD LENGTHS

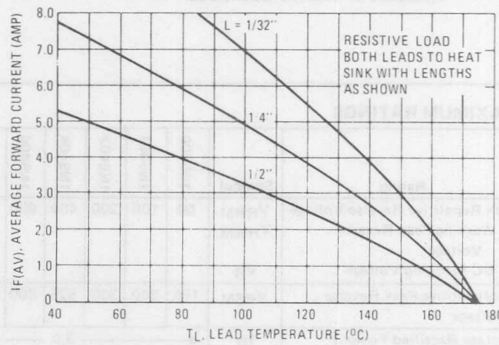
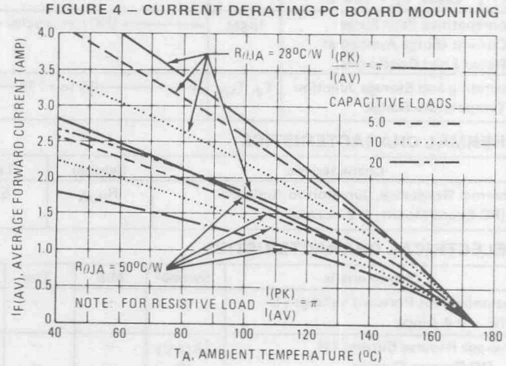


FIGURE 4 – CURRENT DERATING PC BOARD MOUNTING

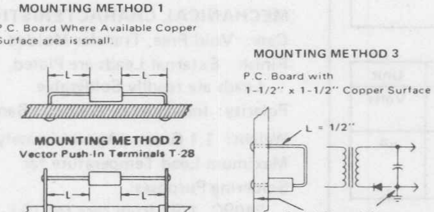


NOTE 1 – AMBIENT MOUNTING DATA

Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN) 1/8	1/4	1/2	3/4	$R_{\theta JA}$
1	50	51	53	55	°C/W
2	58	59	61	63	°C/W
3		28			°C/W



MOTOROLA

1N5817 MBR115P
1N5818 MBR120P
1N5819 MBR130P
MBR140P

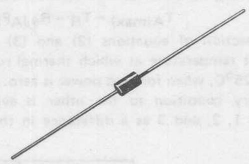
AXIAL LEAD RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency

SCHOTTKY BARRIER RECTIFIERS

1 AMPERE
15, 20, 30, 40 VOLTS



*MAXIMUM RATINGS

Rating	Symbol	MBR115P	1N5817 MBR120P	1N5818 MBR130P	1N5819 MBR140P	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	15	20	30	40	V
Non-Repetitive Peak Reverse Voltage	V_{RSM}	15	24	36	48	V
RMS Reverse Voltage	$V_{R(RMS)}$	10	14	21	28	V
Average Rectified Forward Current (2) ($V_{R(equiv)} \leqslant 0.2\ V_R(dc)$, $T_L = 90^oC$, $R_{\theta JA} = 80^oC/W$, P.C. Board Mounting, see Note 2, $T_A = 55^oC$)	I_O	← 1.0 →				A
Ambient Temperature (Rated $V_R(dc)$, $P_{F(AV)} = 0$, $R_{\theta JA} = 80^oC/W$)	T_A	90	85	80	75	^oC
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions, half-wave, single phase 60 Hz, $T_L = 70^oC$)	I_{FSM}	← 25 (for one cycle) →				A
Operating and Storage Junction Temperature Range (Reverse Voltage applied)	T_J, T_{stg}	← −65 to +125 →				^oC
Peak Operating Junction Temperature (Forward Current applied)	$T_{J(pk)}$	← 150 →				^oC

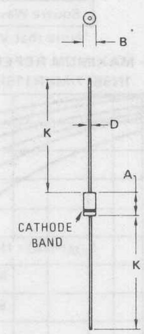
*THERMAL CHARACTERISTICS (Note 2)

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	80	$^oC/W$

*ELECTRICAL CHARACTERISTICS ($T_L = 25^oC$ unless otherwise noted) (2)

Characteristic	Symbol	1N5817	1N5818	1N5819	MBR115P MBR120P MBR130P	MBR140P	Unit
Maximum Instantaneous Forward Voltage (1)							V
(i_F = 0.1 A)	v_F	0.320	0.330	0.340	0.350	0.350	
(i_F = 1.0 A)		0.450	0.550	0.600	0.550	0.600	
(i_F = 3.0 A)		0.750	0.875	0.900	0.850	0.900	
Maximum Instantaneous Reverse Current @ Rated dc Voltage (1)	i_R						mA
($T_L = 25^oC$)		1.0	1.0	1.0	1.0	1.0	
($T_L = 100^oC$)		10	10	10	10	10	

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.
(2) Lead Temperature reference is cathode lead 1/32″ from case.
*Indicates JEDEC Registered Data for 1N5817-19.



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

CASE 59-04

MECHANICAL CHARACTERISTICS

CASE . . . . Void free, transfer molded

FINISH . . . . All external surfaces corrosion-resistant and the terminal leads are readily solderable

POLARITY . . . . Cathode indicated by polarity band

MOUNTING POSITIONS . . . . Any

SOLDERING . . . . .220°C 1/16″ from case for ten seconds

NOTE 1 – DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.1 V_{RWM}. Proper derating may be accomplished by use of equation (1).

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}P_{F(AV)} - R_{\theta JA}P_{R(AV)} \quad (1)$$

where $T_{A(max)}$ = Maximum allowable ambient temperature
$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest)
$P_{F(AV)}$ = Average forward power dissipation
$P_{R(AV)}$ = Average reverse power dissipation
$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1, 2, and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2).

$$T_R = T_{J(max)} - R_{\theta JA}P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2, and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2, and 3 is based upon dc conditions. For use in common rectifier circuits, Table 1 indicates suggested factors for an equivalent dc voltage to use for conservative design, that is:

$$V_{R(equiv)} = V_{in(PK)} \times F \quad (4)$$

The factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

EXAMPLE: Find $T_{A(max)}$ for 1N5818 operated in a 12-volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 0.4 A ($I_{F(AV)}$ = 0.5 A), $I_{(FM)}/I_{(AV)}$ = 10, Input Voltage = 10 $V_{(rms)}$, $R_{\theta JA}$ = 80°C/W.

Step 1. Find $V_{R(equiv)}$. Read F = 0.65 from Table 1,
$\therefore V_{R(equiv)} = (1.41)(10)(0.65) = 9.2$ V.

Step 2. Find T_R from Figure 2. Read T_R = 109°C
@ V_R = 9.2 V and $R_{\theta JA}$ = 80°C/W.

Step 3. Find $P_{F(AV)}$ from Figure 4. **Read $P_{F(AV)}$ = 0.5 W
@ $\frac{I_{(FM)}}{I_{(AV)}}$ = 10 and $I_{F(AV)}$ = 0.5 A.

Step 4. Find $T_{A(max)}$ from equation (3).
$T_{A(max)}$ = 109 – (80) (0.5) = 69°C.

**Values given are for the 1N5818. Power is slightly lower for the 1N5817 because of its lower forward voltage, and higher for the 1N5819. Variations will be similar for the MBR-prefix devices, using $P_{F(AV)}$ from Figure 7.

TABLE 1 – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped*†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

*Note that $V_{R(PK)} \approx 2.0\ V_{in(PK)}$. †Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE
1N5817/MBR115P/MBR120P

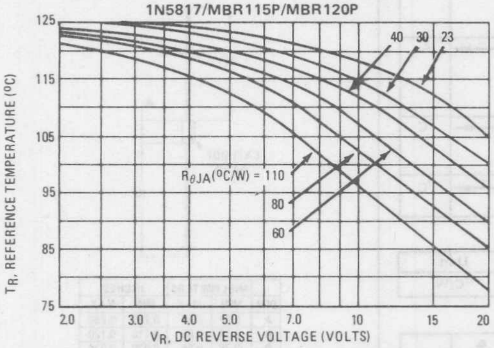


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE
1N5818/MBR130P

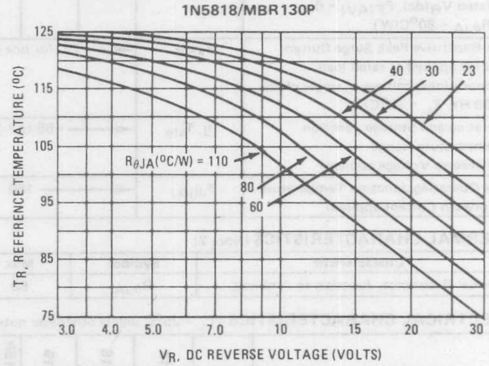


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE
1N5819/MBR140P

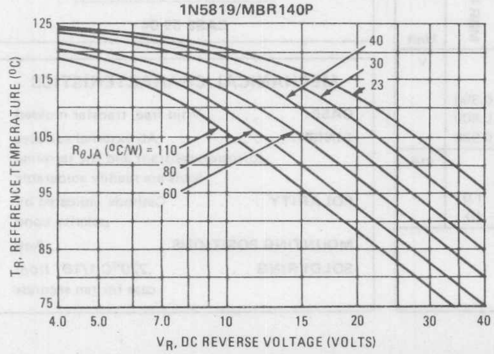
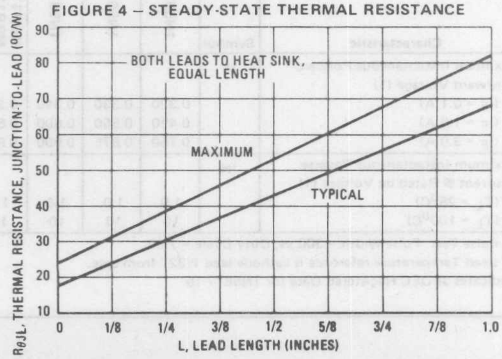


FIGURE 4 – STEADY-STATE THERMAL RESISTANCE



THERMAL CHARACTERISTICS

FIGURE 5 – THERMAL RESPONSE

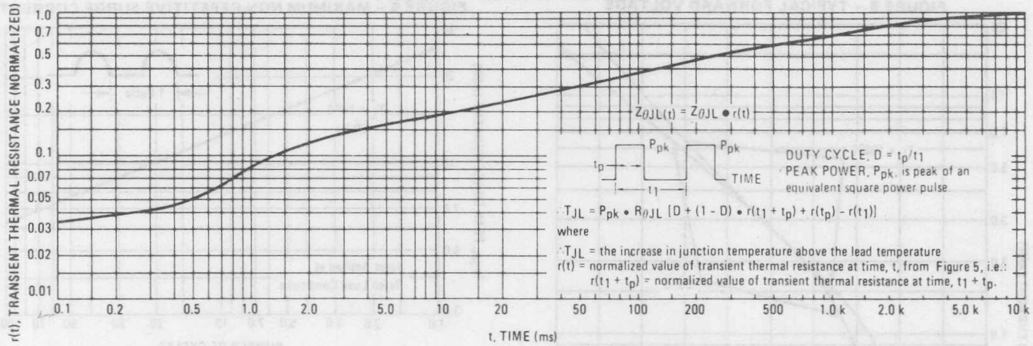


FIGURE 6 – FORWARD POWER DISSIPATION
1N5817-19

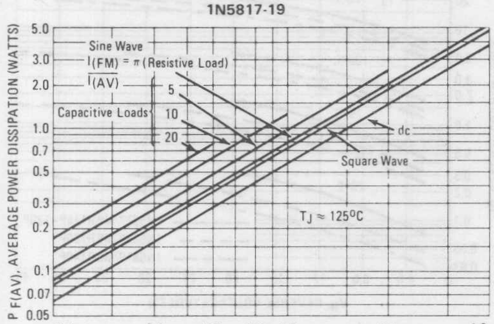
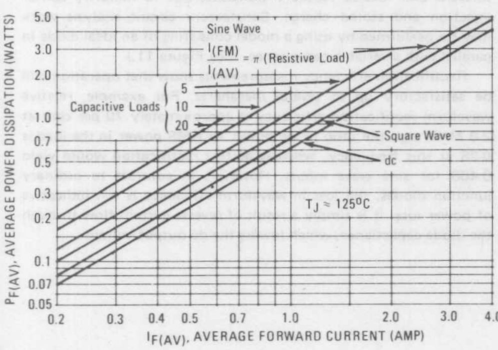


FIGURE 7 – FORWARD POWER DISSIPATION
MBR115P-140P



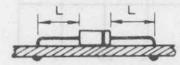
NOTE 2 – MOUNTING DATA

Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering, or in case the tie point temperature cannot be measured.

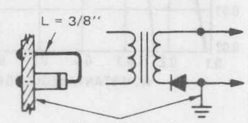
TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

Mounting Method	Lead Length, L (in)				$R_{\theta JA}$
	1/8	1/4	1/2	3/4	
1	52	65	72	85	°C/W
2	67	80	87	100	°C/W
3		50			°C/W

Mounting Method 1
P.C. Board with
1-1/2" X 1-1/2"
copper surface.

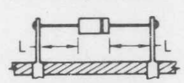


Mounting Method 3
P.C. Board with
1-1/2" X 1-1/2"
copper surface.



Board Ground Plane

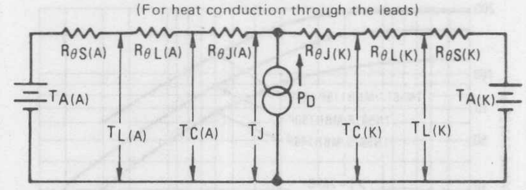
Mounting Method 2



Vector Pin Mounting

NOTE 3 – THERMAL CIRCUIT MODEL

(For heat conduction through the leads)



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature T_C = Case Temperature
T_L = Lead Temperature T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Power Dissipation

(Subscripts A and K refer to anode and cathode sides, respectively.) Values for thermal resistance components are:

$R_{\theta L}$ = 100°C/W/in typically and 120°C/W/in maximum
$R_{\theta J}$ = 36°C/W typically and 46°C/W maximum.

FIGURE 8 – TYPICAL FORWARD VOLTAGE

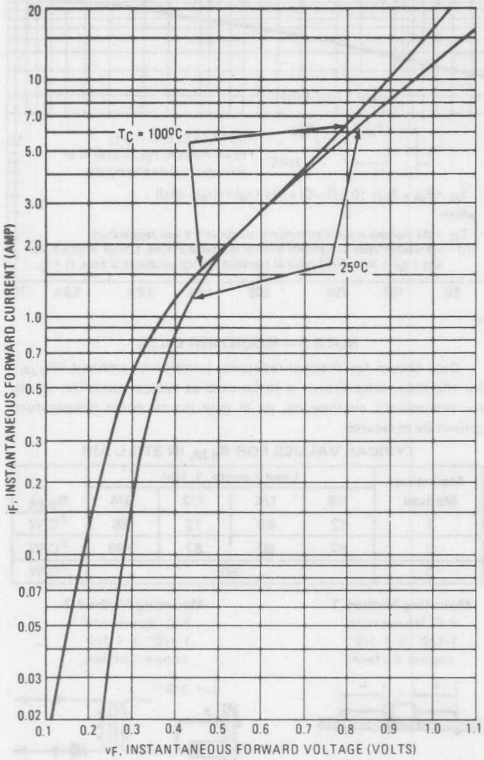


FIGURE 9 – MAXIMUM NON-REPETITIVE SURGE CURRENT

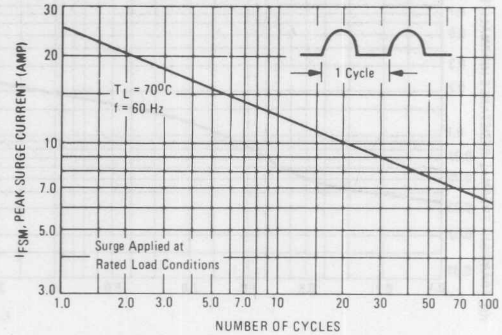


FIGURE 10 – TYPICAL REVERSE CURRENT

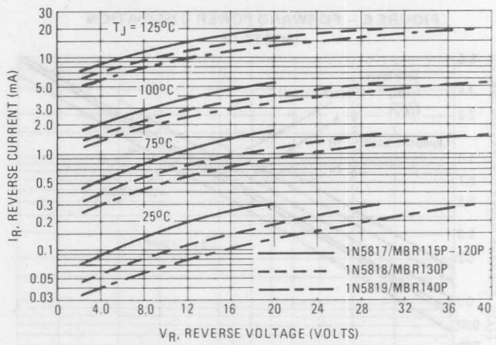
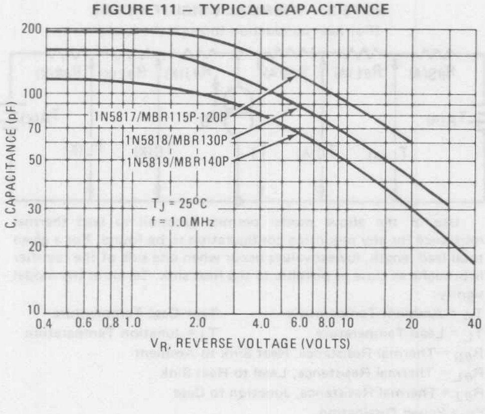


FIGURE 11 – TYPICAL CAPACITANCE



NOTE 4 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to jucntion diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 11.)

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss: it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

MOTOROLA

1N5820 MBR320P
1N5821 MBR330P
1N5822 MBR340P

Designers Data Sheet

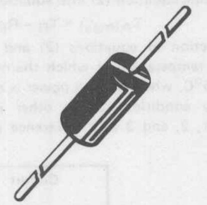
AXIAL LEAD RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Power Loss/High Efficiency
- Low Stored Charge, Majority Carrier Conduction

SCHOTTKY BARRIER RECTIFIERS

3.0 AMPERES
20, 30, 40 VOLTS



Designer's Data for Worst-Case Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves—representing boundaries on device characteristics—are given to facilitate worst-case design.

*MAXIMUM RATINGS

Rating	Symbol	1N5820 MBR320P	1N5821 MBR330P	1N5822 MBR340P	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	V
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	V
RMS Reverse Voltage	$V_{R(RMS)}$	14	21	28	V
Average Rectified Forward Current (2) $V_{R(equiv)} \leq 0.2\ V_{R(dc)}$, $T_L = 95^oC$ ($R_{\theta JA} = 28^oC/W$, P.C. Board Mounting, see Note 2)	I_O	←	3.0	→	A
Ambient Temperature Rated $V_{R(dc)}$, $P_{F(AV)} = 0$ $R_{\theta JA} = 28^oC/W$	T_A	90	85	80	^oC
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions, half wave, single phase 60 Hz, $T_L = 75^oC$)	I_{FSM}	←	80 (for one cycle)	→	A
Operating and Storage Junction Temperature Range (Reverse Voltage applied)	T_J, T_{stg}	←	−65 to +125	→	^oC
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	←	150	→	^oC

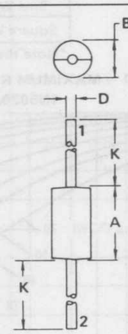
*THERMAL CHARACTERISTICS (Note 2)

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	28	$^oC/W$

*ELECTRICAL CHARACTERISTICS ($T_L = 25^oC$ unless otherwise noted) (2)

Characteristic	Symbol	1N5820	1N5821	1N5822	MBR---P	Unit
Maximum Instantaneous Forward Voltage (1)	v_F					V
(i_F = 1.0 Amp)		0.370	0.380	0.390	0.400	
(i_F = 3.0 Amp)		0.475	0.500	0.525	0.550	
(i_F = 9.4 Amp)		0.850	0.900	0.950	0.950	
Maximum Instantaneous Reverse Current @ Rated dc Voltage (1)	i_R					mA
$T_L = 25^oC$		2.0	2.0	2.0	2.0	
$T_L = 100^oC$		20	20	20	20	

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.
(2) Lead Temperature reference is cathode lead 1/32" from case.
*Indicates JEDEC Registered Data for 1N5820-22.



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	9.65	0.370	0.380
B	4.83	5.33	0.190	0.210
D	1.22	1.32	0.048	0.052
K	26.97	27.23	1.062	1.072

CASE 267-01

MECHANICAL CHARACTERISTICS

CASE . . . . Void free, transfer molded
FINISH . . . . .All external surfaces corrosion-resistant and the terminal leads are readily solderable
POLARITY . . . . Cathode indicated by polarity band
MOUNTING POSITIONS . . . . Any
SOLDERING . . . . . . 220°C 1/16" from case for ten seconds

NOTE 1 – DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.1 V_{RWM}. Proper derating may be accomplished by use of equation (1).

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}P_{F(AV)} - R_{\theta JA}P_{R(AV)} \quad (1)$$

where $T_{A(max)}$ = Maximum allowable ambient temperature
$T_{J(max)}$ = Maximum allowable junction temperature ($125^{o}C$ or the temperature at which thermal runaway occurs, whichever is lowest)
$P_{F(AV)}$ = Average forward power dissipation
$P_{R(AV)}$ = Average reverse power dissipation
$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1, 2, and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2).

$$T_R = T_{J(max)} - R_{\theta JA}P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where $T_J = 125^{o}C$, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2, and 3 as a difference in the rate of change of the slope in the vicinity of $115^{o}C$. The data of Figures 1, 2, and 3 is based upon dc conditions. For use in common rectifier circuits, Table 1 indicates suggested factors for an equivalent dc voltage to use for conservative design, that is:

$$V_{R(equiv)} = V_{(FM)} \times F \quad (4)$$

The factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

EXAMPLE: Find $T_{A(max)}$ for 1N5821 operated in a 12-volt dc supply using a bridge circuit with capacitive filter such that $I_{DC} = 2.0$ A ($I_{F(AV)} = 1.0$ A), $I_{(FM)}/I_{(AV)} = 10$, Input Voltage = 10 $V_{(rms)}$, $R_{\theta JA} = 40^{o}C/W$.

Step 1. Find $V_{R(equiv)}$. Read F = 0.65 from Table 1,
$\therefore V_{R(equiv)} = (1.41)(10)(0.65) = 9.2$ V.

Step 2. Find T_R from Figure 2. Read $T_R = 108^{o}C$
@ $V_R = 9.2$ V and $R_{\theta JA} = 40^{o}C/W$.

Step 3. Find $P_{F(AV)}$ from Figure 6. **Read $P_{F(AV)} = 0.85$ W
@ $\frac{I_{(FM)}}{I_{(AV)}} = 10$ and $I_{F(AV)} = 1.0$ A.

Step 4. Find $T_{A(max)}$ from equation (3).
$T_{A(max)} = 108 - (0.85)(40) = 74^{o}C$.

**Values given are for the 1N5821. Power is slightly lower for the 1N5820 because of its lower forward voltage, and higher for the 1N5822. Variations will be similar for the MBR-prefix devices, using $P_{F(AV)}$ from Figure 7.

TABLE 1 – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped*†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

*Note that $V_{R(PK)} \approx 2.0\ V_{in(PK)}$. †Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE 1N5820/MBR320P

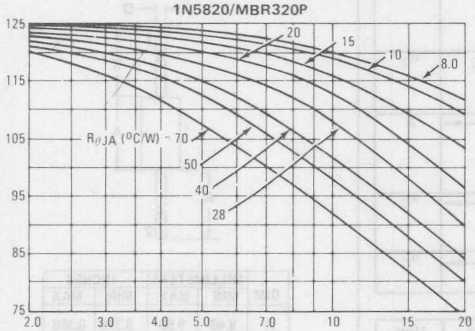


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE 1N5821/MBR330P

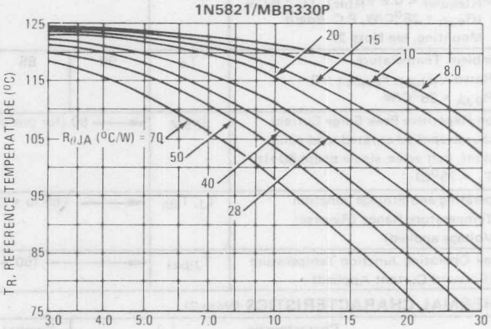


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE 1N5822/MBR340P

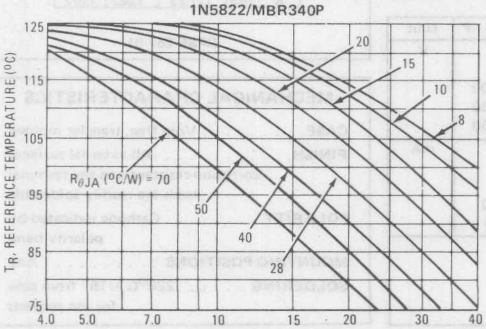
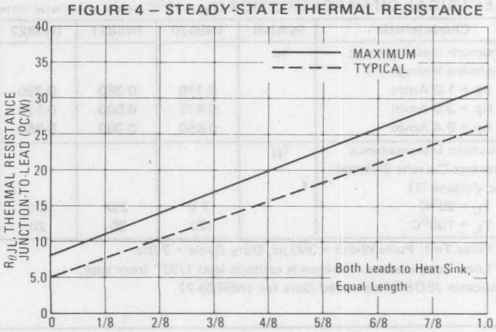


FIGURE 4 – STEADY-STATE THERMAL RESISTANCE



1N5820, 1N5821, 1N5822, MBR320P, MBR330P, MBR340P

FIGURE 5 – THERMAL RESPONSE

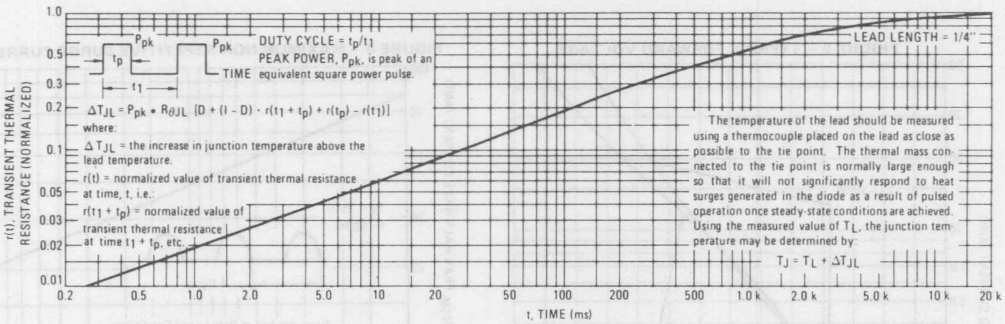


FIGURE 6 – FORWARD POWER DISSIPATION
1N5820-22

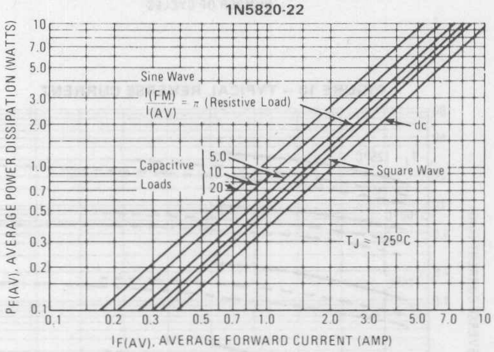
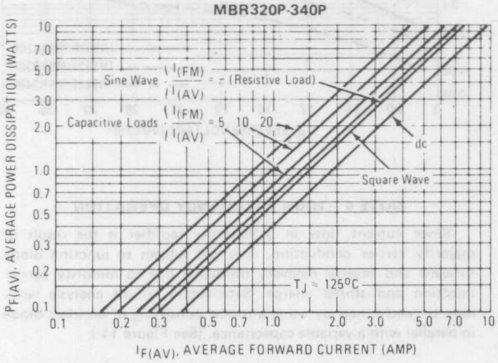
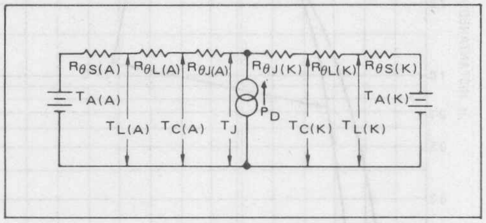


FIGURE 7 – FORWARD POWER DISSIPATION
MBR320P-340P



NOTE 3 – APPROXIMATE THERMAL CIRCUIT MODEL



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature T_C = Case Temperature
T_L = Lead Temperature T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Total Power Dissipation = $P_F + P_R$
P_F = Forward Power Dissipation
P_R = Reverse Power Dissipation

(Subscripts (A) and (K) refer to anode and cathode sides, respectively.) Values for thermal resistance components are:
$R_{\theta L}$ = 42°C/W/in typically and 48°C/W/in maximum
$R_{\theta J}$ = 10°C/W typically and 16°C/W maximum

The maximum lead temperature may be found as follows:

$$T_L = T_{J(max)} - \Delta T_{JL}$$

where $\Delta T_{JL} \approx R_{\theta JL} \cdot P_D$

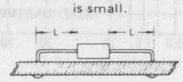
NOTE 2 – MOUNTING DATA

Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering, or in case the tie point temperature cannot be measured.

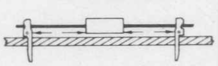
TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

Mounting Method	Lead Length, L (in) 1/8	1/4	1/2	3/4	$R_{\theta JA}$
1	50	51	53	55	°C/W
2	58	59	61	63	°C/W
3	28				°C/W

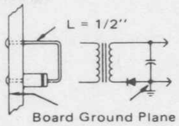
Mounting Method 1
P.C. Board where available copper surface is small.



Mounting Method 2
Vector Push-In Terminals T-28



Mounting Method 3
P.C. Board with 2-1/2″ X 2-1/2″ copper surface.



Board Ground Plane

FIGURE 8 – TYPICAL FORWARD VOLTAGE

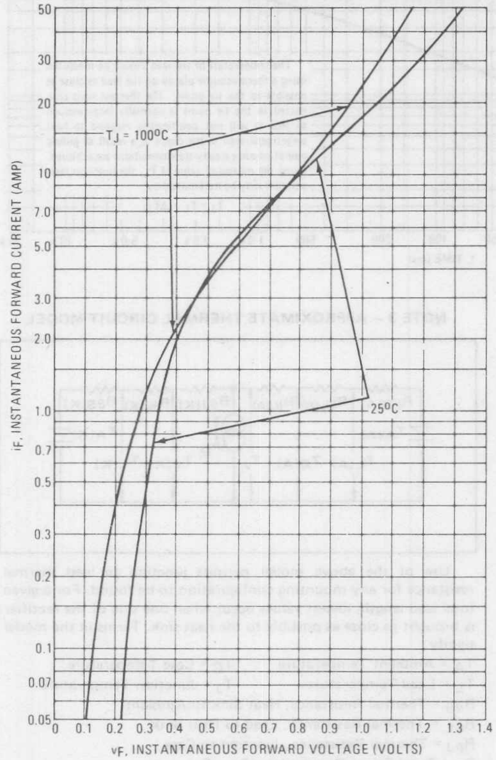


FIGURE 9 – MAXIMUM NON-REPETITIVE SURGE CURRENT

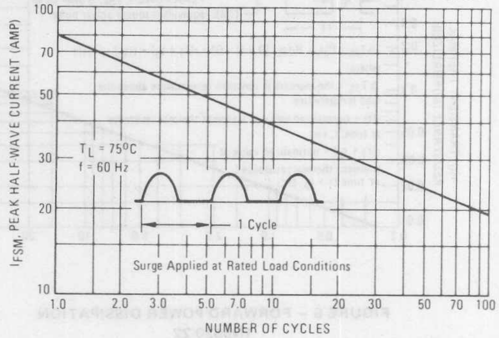


FIGURE 10 – TYPICAL REVERSE CURRENT

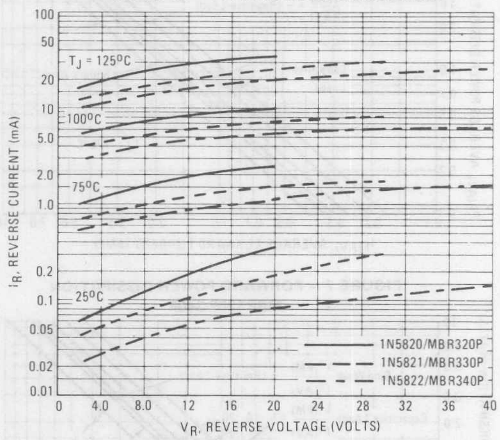
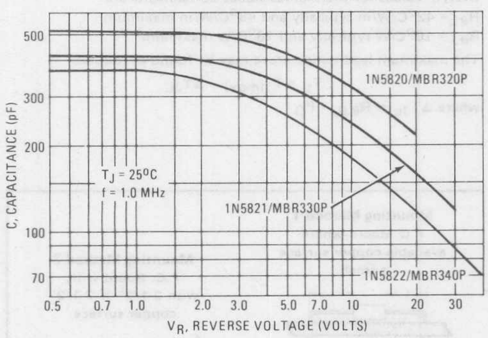


FIGURE 11 – TYPICAL CAPACITANCE



NOTE 4 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 11.)

MOTOROLA

1N5823 1N5824 1N5825 MBR5825H, H1

Designers Data Sheet

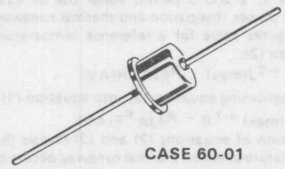
HOT CARRIER POWER RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free-wheeling diodes, and polarity-protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/ High Efficiency
- High Surge Capacity
- TX Version Available

SCHOTTKY BARRIER RECTIFIERS

5 AMPERES
20, 30, 40 VOLTS



CASE 60-01

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

*MAXIMUM RATINGS

Rating	Symbol	1N5823	1N5824	1N5825 MBR5825H, H1	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	14	21	28	Volts
Average Rectified Forward Current $V_{R(equiv)} \leqslant 0.2\ V_{R\ (dc)}$, $T_C = 75°C$ $V_{R(equiv)} \leqslant 0.2\ V_{R\ (dc)}$, $T_L = 80°C$ $R_{\theta JA} = 25°C/W$, P.C. Board Mounting, See Note 3)	I_O	← 15 → ← 5.0 →			Amp
Ambient Temperature Rated $V_{R\ (dc)}$, $P_{F(AV)} = 0$ $R_{\theta JA} = 25°C/W$	T_A	65	60	55	°C
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase 60 Hz)	I_{FSM}	← 500 (for 1 cycle) →			Amp
Operating and Storage Junction Temperature Range (Reverse Voltage applied)	T_J, T_{stg}	← -65 to +125 →			°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	← 150 →			°C

*THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	3.0	°C/W

*ELECTRICAL CHARACTERISTICS ($T_C = 25°C$ unless otherwise noted)

Characteristic	Symbol	1N5823	1N5824	1N5825 MBR5825H, H1	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 3.0 Amp) (i_F = 5.0 Amp) (i_F = 15.7 Amp)	v_F	 0.330 0.360 0.470	 0.340 0.370 0.490	 0.350 0.380 0.520	Volts
Maximum Instantaneous Reverse Current @ rated dc Voltage $T_C = 25°C$ $T_C = 100°C$	i_R	 10 75	 10 75	 10 75	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0% *Indicates JEDEC Registered Data for 1N5823-1N5825

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.1 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA} P_{F(AV)} - R_{\theta JA} P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1, 2 and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA} P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA} P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2 and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2 and 3 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{IN(PK)} \times F \quad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for 1N5825 operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 10 A ($I_{F(AV)}$ = 5 A), $I_{(PK)}/I_{(AV)}$ = 10, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 10°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴
$V_{R(equiv)}$ = (1.41)(10)(0.65) = 9.2 V

Step 2: Find T_R from Figure 3. Read T_R = 113°C @ V_R = 9.2 V & $R_{\theta JA}$ = 10°C/W.

Step 3: Find $P_{F(AV)}$ from Figure 4. **Read $P_{F(AV)}$ = 5.5 W @ $\frac{I_{(PK)}}{I_{(AV)}}$ = 10 & $I_{F(AV)}$ = 5 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 113-(10)(5.5) = 58°C.

**Value given are for the 1N5825. Power is slightly lower for the other units because of their lower forward voltage.

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped *†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

*Note that $V_{R(PK)} \approx 2\, V_{in(PK)}$ †Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE – 1N5823

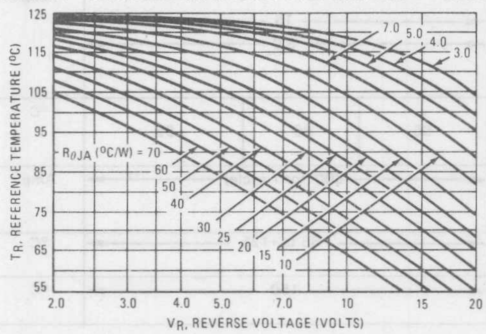


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE – 1N5824

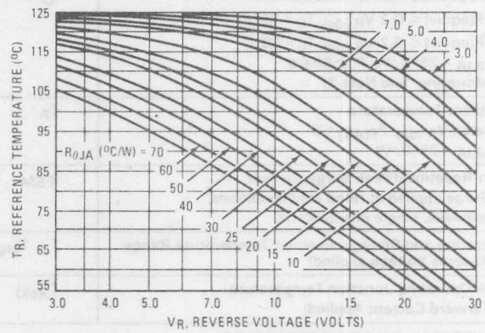


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE 1N5825 AND MBR5825H, H1

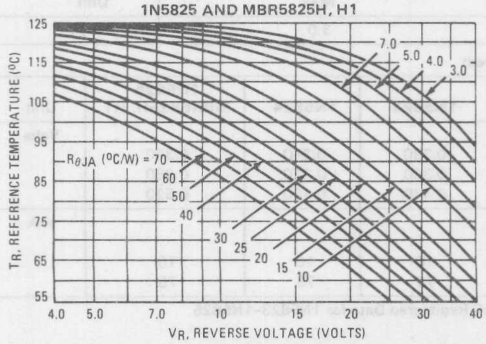
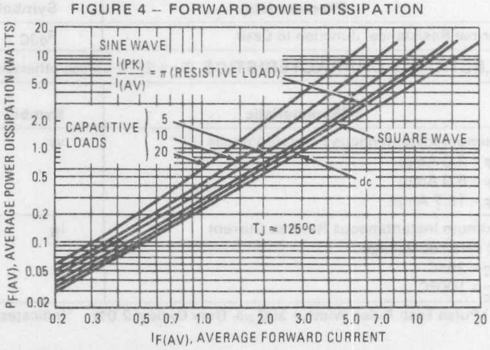
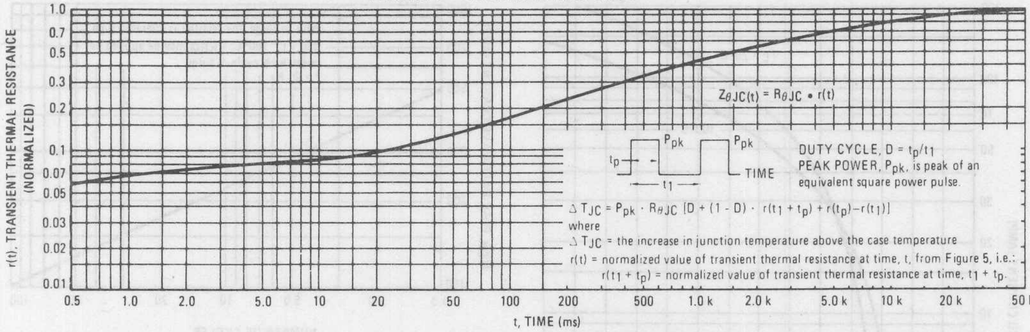


FIGURE 4 – FORWARD POWER DISSIPATION

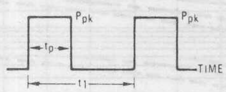


THERMAL CHARACTERISTICS

FIGURE 5 – THERMAL RESPONSE



NOTE 2 – FINDING JUNCTION TEMPERATURE



DUTY CYCLE, $D = t_p / t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 5 i.e.

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

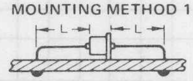
NOTE 3 – MOUNTING DATA

Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering.

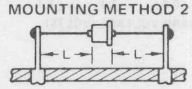
TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN) 1/4	1	$R_{\theta JA}$
1	55	60	°C/W
2	65	70	°C/W
3	25		°C/W

MOUNTING METHOD 1



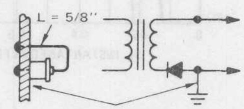
MOUNTING METHOD 2



Vector pin mounting

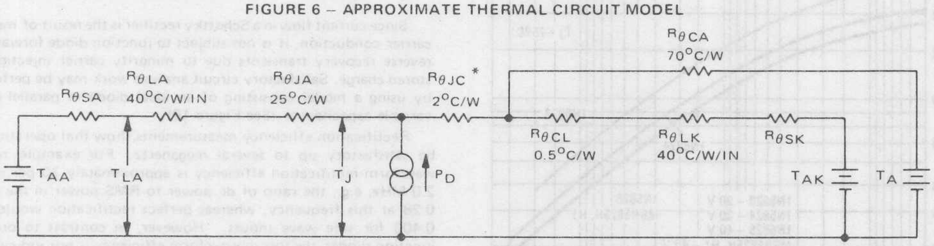
MOUNTING METHOD 3

P. C. Board with 2 1/2" x 2 1/2" copper surface



Board Ground Plane

FIGURE 6 – APPROXIMATE THERMAL CIRCUIT MODEL



Use of the above model permits calculation of average junction temperature for any mounting situation. Lowest values of thermal resistance will occur when the cathode lead is brought as close as possible to a heat dissipator; as heat conduction through the anode lead is small. Terms in the model are defined as follows:

*Case temperature reference is at cathode end.

TEMPERATURES

- T_A = Ambient
- T_{AA} = Anode Heat Sink Ambient
- T_{AK} = Cathode Heat Sink Ambient
- T_{LA} = Anode Lead
- T_{LK} = Cathode Lead
- T_J = Junction

THERMAL RESISTANCES

- $R_{\theta CA}$ = Case to Ambient
- $R_{\theta SA}$ = Anode Lead Heat Sink to Ambient
- $R_{\theta SK}$ = Cathode Lead Heat Sink to Ambient
- $R_{\theta LA}$ = Anode Lead
- $R_{\theta LK}$ = Cathode Lead
- $R_{\theta CL}$ = Case to Cathode Lead
- $R_{\theta JC}$ = Junction to Case
- $R_{\theta JA}$ = Junction to Anode Lead (S bend)

FIGURE 7 – TYPICAL FORWARD VOLTAGE

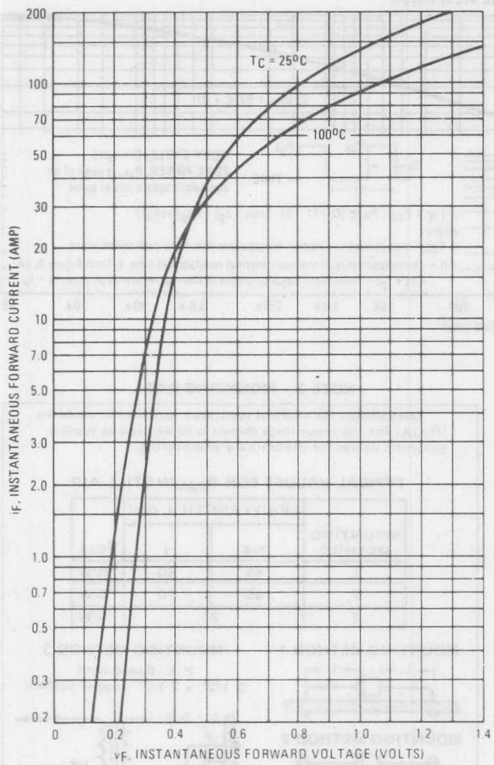


FIGURE 8 – MAXIMUM SURGE CAPABILITY

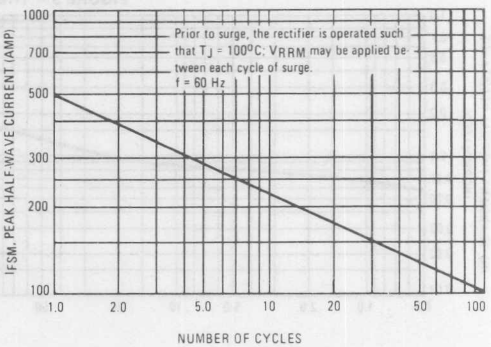


FIGURE 9 – TYPICAL REVERSE CURRENT

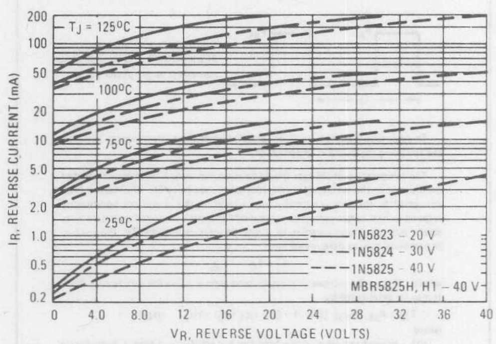
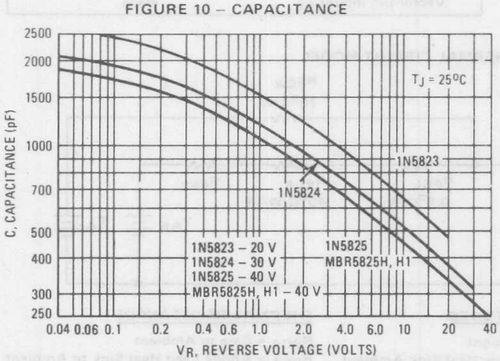


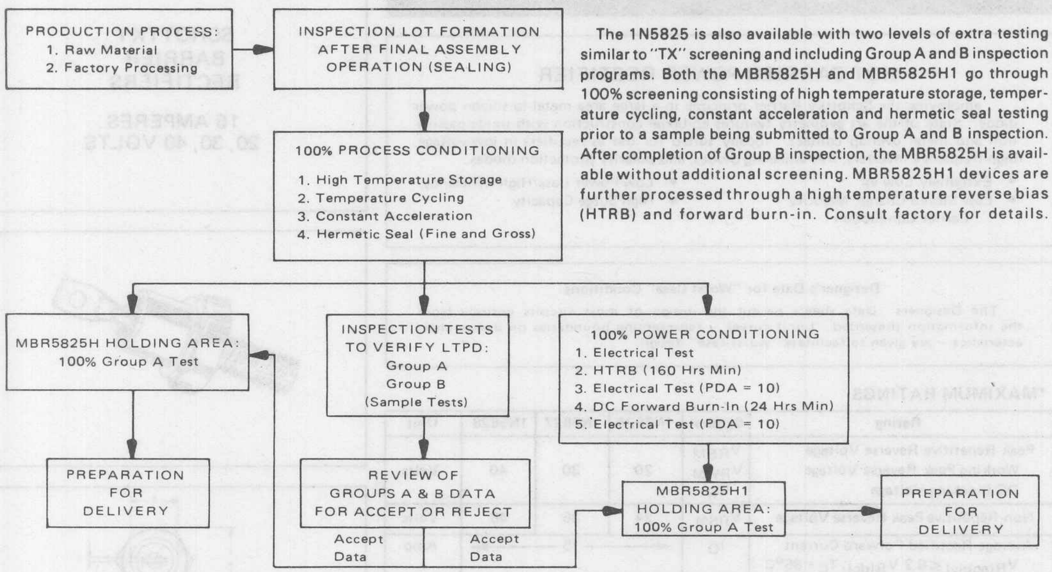
FIGURE 10 – CAPACITANCE



NOTE 4 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 10).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

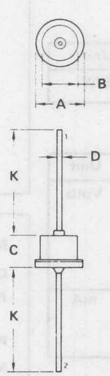


NOTE 5 – HI-REL PROGRAM OPTIONS

The 1N5825 is also available with two levels of extra testing similar to "TX" screening and including Group A and B inspection programs. Both the MBR5825H and MBR5825H1 go through 100% screening consisting of high temperature storage, temperature cycling, constant acceleration and hermetic seal testing prior to a sample being submitted to Group A and B inspection. After completion of Group B inspection, the MBR5825H is available without additional screening. MBR5825H1 devices are further processed through a high temperature reverse bias (HTRB) and forward burn-in. Consult factory for details.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed construction.
FINISH: All external surfaces corrosion-resistant and the terminal leads are readily solderable.
WEIGHT: 2.4 grams (approximately).
POLARITY: Cathode to case.
MOUNTING POSITONS: Any



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	–	11.43	–	0.450
B	–	8.89	–	0.350
C	–	7.62	–	0.300
D	1.17	1.42	0.046	0.056
K	24.89	–	0.980	–

CASE 60-1

MOTOROLA

1N5826
1N5827
1N5828

Designers Data Sheet

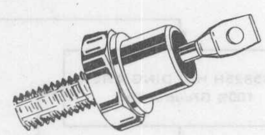
HOT CARRIER POWER RECTIFIER

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity

SCHOTTKY BARRIER RECTIFIERS

15 AMPERES
20, 30, 40 VOLTS



Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

*MAXIMUM RATINGS

Rating	Symbol	1N5826	1N5827	1N5828	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	Volts
Average Rectified Forward Current $V_{R(equiv)} \leq 0.2\ V_{R(dc)}$, $T_C = 85°C$	I_O	←	15	→	Amp
Ambient Temperature Rated $V_{R(dc)}$, $P_{F(AV)} = 0$, $R_{\theta JA} = 5.0°C/W$	T_A	95	90	85	°C
Non-Repetitive Peak Surge Current (surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	←	500 (for 1 cycle)	→	Amp
Operating and Storage Junction Temperature Range (Reverse voltage applied)	T_J, T_{stg}	←	−65 to +125	→	°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	←	150	→	°C

*THERMAL CHARACTERISTICS

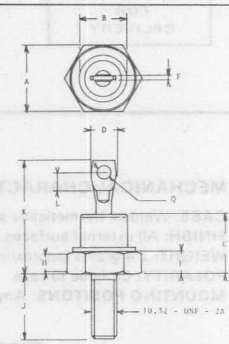
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	2.5	°C/W

*ELECTRICAL CHARACTERISTICS ($T_C = 25°C$ unless otherwise noted.)

Characteristic	Symbol	1N5826	1N5827	1N5828	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 8.0 Amp) (i_F = 15 Amp) (i_F = 47.1 Amp)	v_F	 0.380 0.440 0.670	 0.400 0.470 0.770	 0.420 0.500 0.870	Volts
Maximum Instantaneous Reverse Current @ rated dc Voltage (1) $T_C = 100°C$	i_R	 10 75	 10 75	 10 75	mA

*Indicates JEDEC Registered Data.

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.



DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56
DO-4

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and terminal leads are readily solderable.

POLARITY: Cathode to Case

MOUNTING POSITION: Any

STUD TORQUE: 15 in. lb. max

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}\,P_{F(AV)} - R_{\theta JA}\,P_{R(AV)} \qquad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1, 2 and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA}\,P_{R(AV)} \qquad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}\,P_{F(AV)} \qquad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2 and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2 and 3 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \qquad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for 1N5828 operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 10 A ($I_{F(AV)}$ = 5 A), $I_{(PK)}/I_{(AV)}$ = 20, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 5°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴ $V_{R(equiv)}$ = (1.41)(10)(0.65) = 9.18 V

Step 2: Find T_R from Figure 3. Read T_R = 121°C @ V_R = 9.18 & $R_{\theta JA}$ = 5°C/W

Step 3: Find $P_{F(AV)}$ from Figure 4.** Read $P_{F(AV)}$ = 10 W @ $\frac{I_{(PK)}}{I_{(AV)}}$ = 20 & $I_{F(AV)}$ = 5 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 121-(5)(10) = 71°C

** Value given are for the 1N5828. Power is slightly lower for the other units because of their lower forward voltage.

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped *†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

*Note that $V_{R(PK)} \approx 2\,V_{in(PK)}$

*†Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE – 1N5826

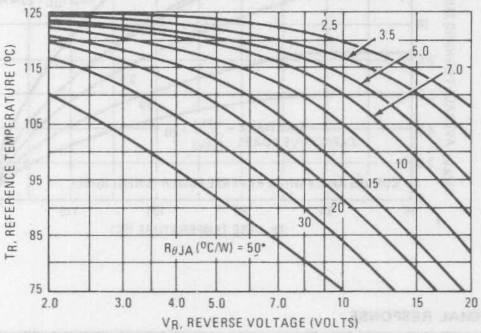


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE – 1N5827

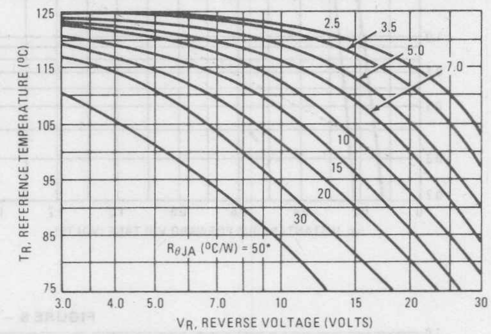


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE – 1N5828

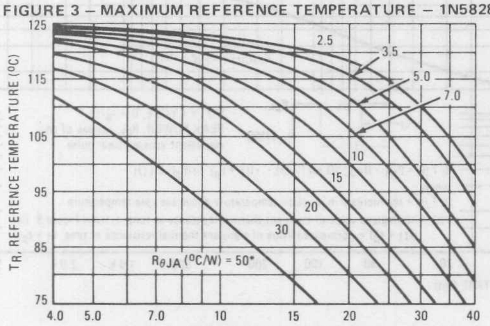
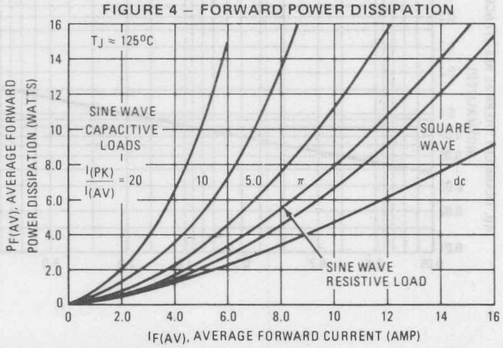


FIGURE 4 – FORWARD POWER DISSIPATION



*No external heat sink.

FIGURE 5 – TYPICAL FORWARD VOLTAGE

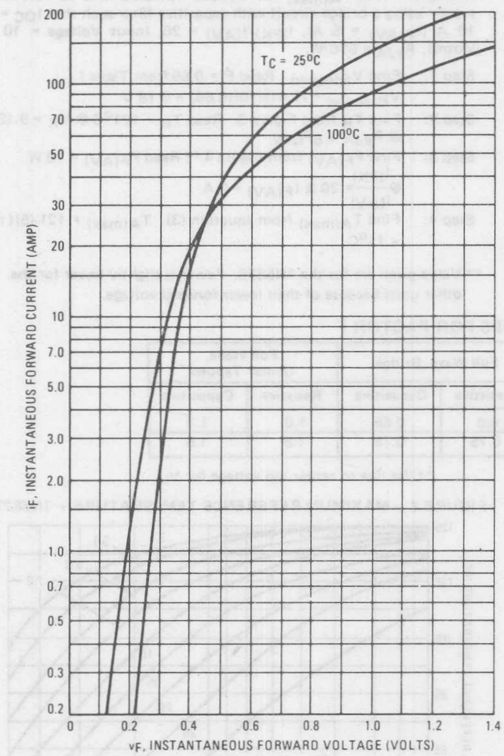


FIGURE 6 – MAXIMUM SURGE CAPABILITY

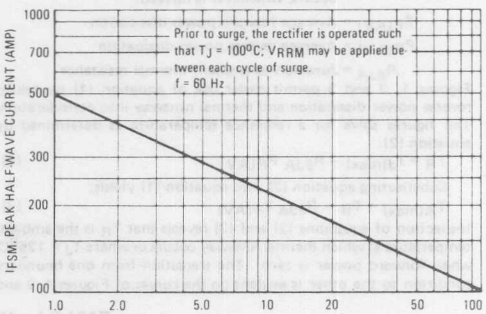


FIGURE 7 – CURRENT DERATING

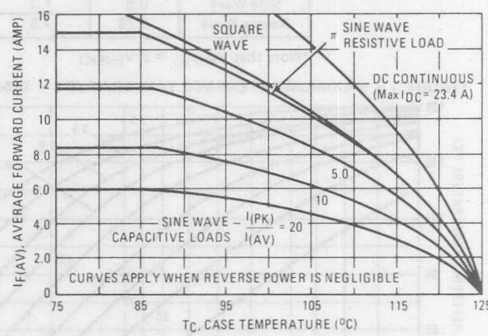


FIGURE 8 – THERMAL RESPONSE

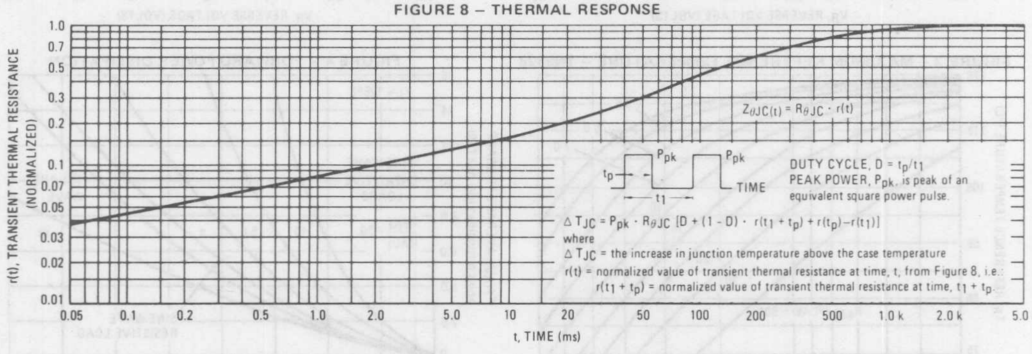


FIGURE 9 – NORMALIZED REVERSE CURRENT

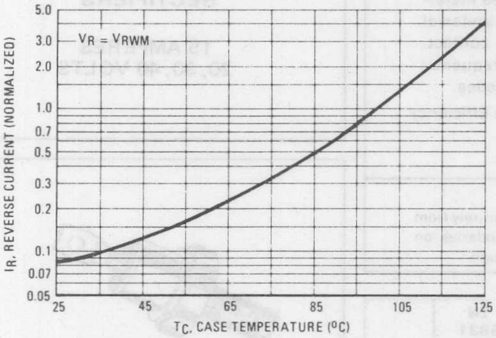


FIGURE 10 – TYPICAL REVERSE CURRENT

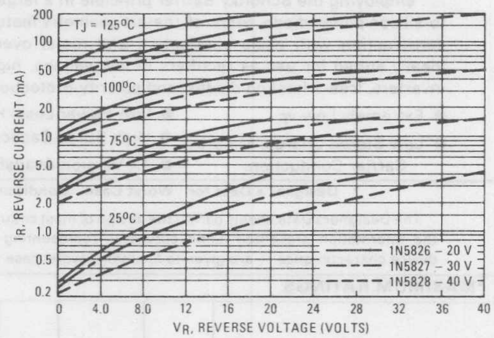
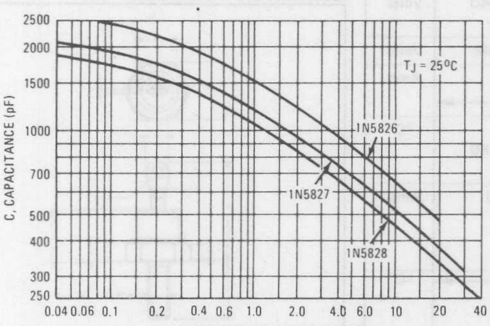


FIGURE 11 – CAPACITANCE



NOTE 2 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 11).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

MOTOROLA

1N5829 1N5830
1N5831
MBR5831H, H1

Designers Data Sheet

HOT CARRIER POWER RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free-wheeling diodes, and polarity-protection diodes.

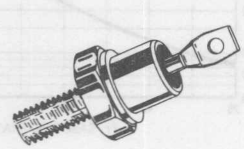
- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity
- TX Version Available

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

SCHOTTKY BARRIER RECTIFIERS

15 AMPERES
20, 30, 40 VOLTS



*MAXIMUM RATINGS

Rating	Symbol	1N 5829	1N 5830	1N 5831 MBR 5831H, H1	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	Volts
Average Rectified Forward Current $V_{R(equiv)} \leqslant 0.2\ V_{R\ (dc)}$, $T_C = 85°C$	I_O		25		Amp
Ambient Temperature Rated $V_{R\ (dc)}$, $P_{F(AV)} = 0$ $R_{\theta JA} = 3.5°C/W$	T_A	90	85	80	°C
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase 60 Hz)	I_{FSM}		800 (for 1 cycle)		Amp
Operating and Storage Junction Temperature Range (Reverse voltage applied	T_J, T_{stg}		-65 to +125		°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$		150		°C

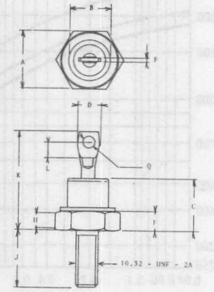
*THERMAL CHARACTERISTICS

Characteristic	Symbol	Max.	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.75	°C/W

*ELECTRICAL CHARACTERISTICS ($T_C = 25°C$ unless otherwise noted)

Characteristic	Symbol	1N 5829	1N 5830	1N 5831 MBR 5831H, H1	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 10 Amp) (i_F = 25 Amp) (i_F = 78.5 Amp)	v_F	 0.360 0.440 0.720	 0.370 0.460 0.770	 0.380 0.480 0.820	Volts
Maximum Instantaneous Reverse Current @ Rated dc Voltage (1) ($T_C = 100°C$)	i_R	20 150	20 150	20 150	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0% *Indicates JEDEC Registered Data for 1N5829–1N5831



DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56
DO-4

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed
FINISH: All external surfaces corrosion resistant and terminal leads are readily solderable.
POLARITY: Cathode to Case
MOUNTING POSITIONS: Any
STUD TORQUE: 15 in. lb. Max

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}\,P_{F(AV)} - R_{\theta JA}\,P_{R(AV)} \qquad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JC}$ = Junction-to-ambient thermal resistance

Figures 1, 2 and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA}\,P_{R(AV)} \qquad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}\,P_{F(AV)} \qquad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2 and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2 and 3 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \qquad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for 1N5831 operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 16 A ($I_{F(AV)}$ = 8 A), $I_{(PK)}/I_{(AV)}$ = 20, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 5°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴ $V_{R(equiv)}$ = (1.41)(10)(0.65) = 9.18 V

Step 2: Find T_R from Figure 3. Read T_R = 113°C @ V_R = 9.18 & $R_{\theta JA}$ = 5°C/W

Step 3: Find $P_{F(AV)}$ from Figure 4.** Read $P_{F(AV)}$ = 12.8 W @ $\frac{I_{(PK)}}{I_{(AV)}}$ = 20 & $I_{F(AV)}$ = 8 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 113-(5)(12.8) = 49°C

** Value given are for the 1N5828. Power is slightly lower for the other units because of their lower forward voltage.

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped *†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

*Note that $V_{R(PK)} \approx 2\,V_{in(PK)}$

*†Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE – 1N5829

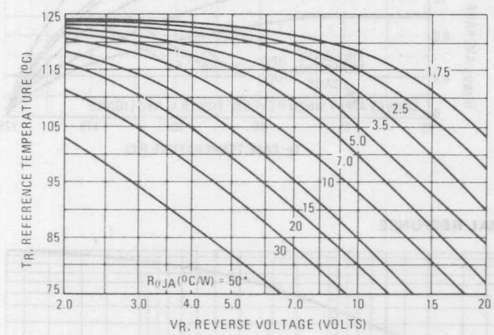


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE – 1N5830

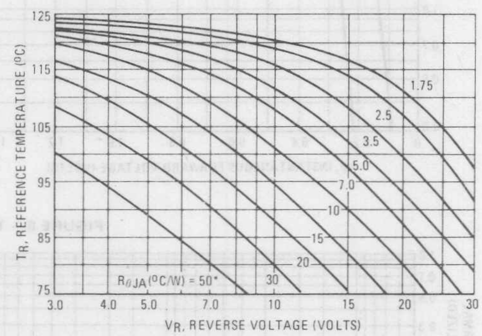


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE 1N5831 AND MBR5831H, H1

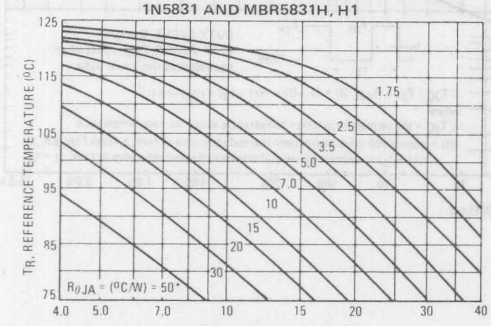
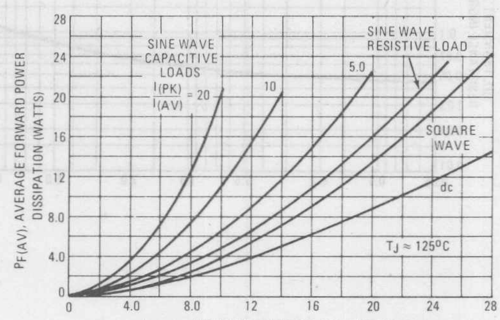


FIGURE 4 – FORWARD POWER DISSIPATION



*No external heat sink.

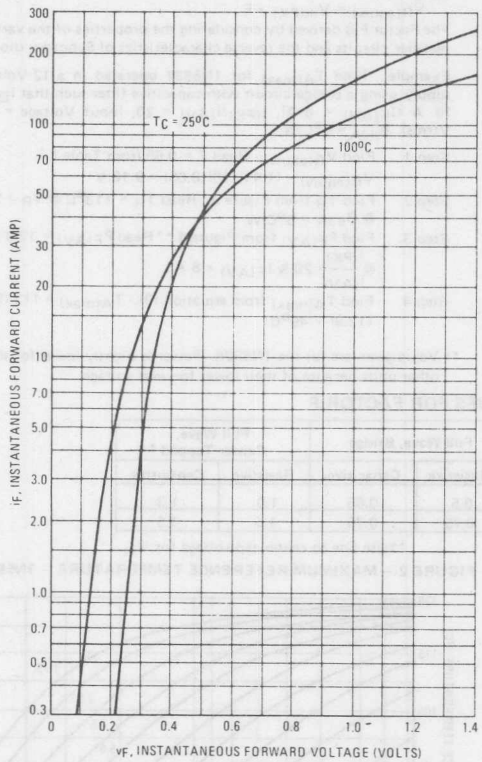


FIGURE 5 – TYPICAL FORWARD VOLTAGE
T_C = 25°C
100°C
i_F, INSTANTANEOUS FORWARD CURRENT (AMP)
v_F, INSTANTANEOUS FORWARD VOLTAGE (VOLTS)

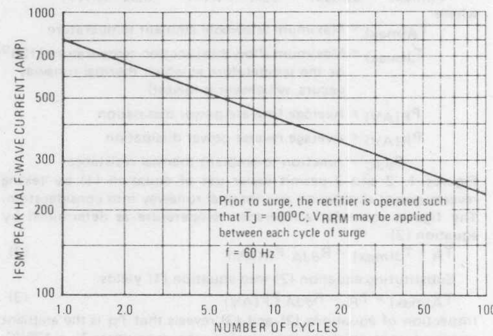


FIGURE 6 – MAXIMUM SURGE CAPABILITY
Prior to surge, the rectifier is operated such that T_J = 100°C; V_{RRM} may be applied between each cycle of surge
f = 60 Hz
I_{FSM}, PEAK HALF WAVE CURRENT (AMP)
NUMBER OF CYCLES

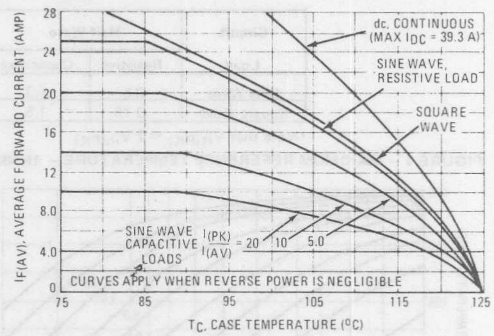


FIGURE 7 – CURRENT DERATING
dc, CONTINUOUS (MAX I_{DC} = 39.3 A)
SINE WAVE, RESISTIVE LOAD
SQUARE WAVE
SINE WAVE CAPACITIVE LOADS $\frac{I_{(PK)}}{I_{(AV)}}$ = 20 10 5.0
CURVES APPLY WHEN REVERSE POWER IS NEGLIGIBLE
$I_{F(AV)}$, AVERAGE FORWARD CURRENT (AMP)
T_C, CASE TEMPERATURE (°C)

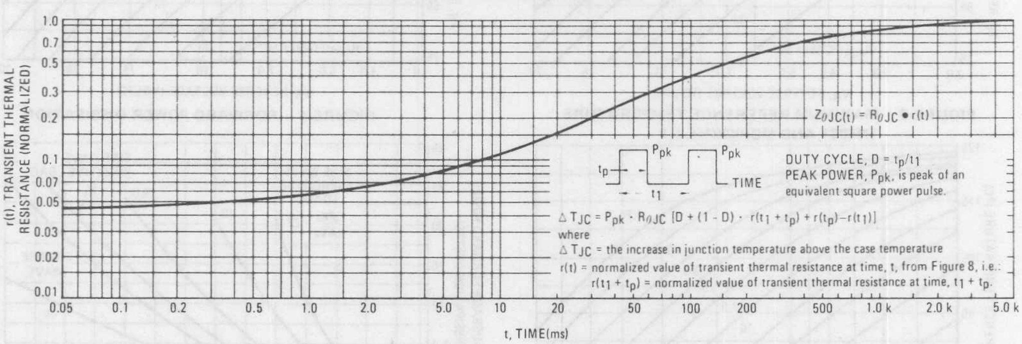


FIGURE 8 – THERMAL RESPONSE
r(t), TRANSIENT THERMAL RESISTANCE (NORMALIZED)
$Z_{\theta JC(t)} = R_{\theta JC} \bullet r(t)$
DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.
$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC}\ [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$
where
ΔT_{JC} = the increase in junction temperature above the case temperature
r(t) = normalized value of transient thermal resistance at time, t, from Figure 8, i.e.:
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time, $t_1 + t_p$.
t, TIME(ms)

FIGURE 9 – NORMALIZED REVERSE CURRENT

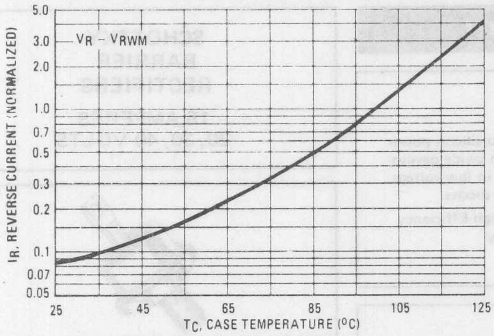


FIGURE 10 – TYPICAL REVERSE CURRENT

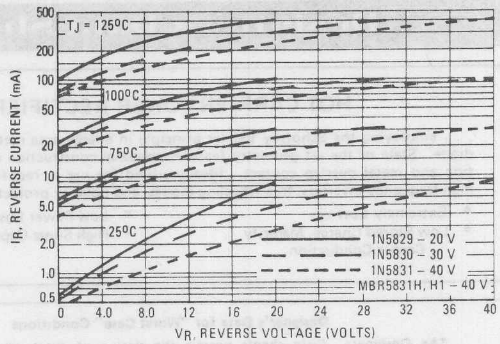
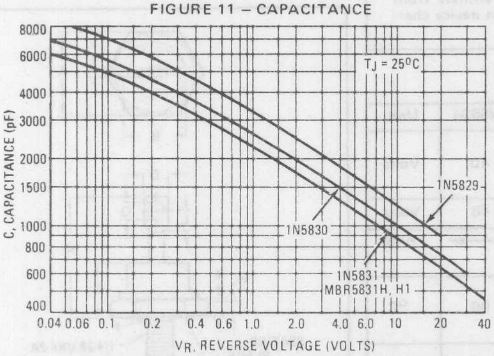


FIGURE 11 – CAPACITANCE



NOTE 2 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 11).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

NOTE 3 – HI-REL PROGRAM OPTIONS

PRODUCTION PROCESS:
1. Raw Material
2. Factory Processing

INSPECTION LOT FORMATION AFTER FINAL ASSEMBLY OPERATION (SEALING)

100% PROCESS CONDITIONING
1. High Temperature Storage
2. Temperature Cycling
3. Constant Acceleration
4. Hermetic Seal (Fine and Gross)

INSPECTION TESTS TO VERIFY LTPD:
Group A
Group B
(Sample Tests)

MBR5831H HOLDING AREA: 100% Group A Test

PREPARATION FOR DELIVERY

REVIEW OF GROUPS A & B DATA FOR ACCEPT OR REJECT

Accept Data

Accept Data

100% POWER CONDITIONING
1. Electrical Test
2. HTRB (160 Hrs Min)
3. Electrical Test (PDA = 10)
4. DC Forward Burn-In (24 Hrs Min)
5. Electrical Test (PDA = 10)

MBR5831H1 HOLDING AREA: 100% Group A Test

PREPARATION FOR DELIVERY

The 1N5831 is also available with two levels of extra testing similar to "TX" screening and including Group A and B inspection programs. Both the MBR5831H and MBR5831H1 go through 100% screening consisting of high temperature storage, temperature cycling, constant acceleration and hermetic seal testing prior to a sample being submitted to Group A and B inspection. After completion of Group B inspection, the MBR5831H is available without additional screening. MBR5831H1 devices are further processed through a high temperature reverse bias (HTRB) and forward burn-in. Consult factory for details.

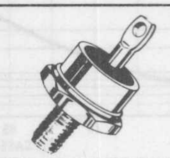
MOTOROLA

1N5832
1N5833
1N5834

Designers Data Sheet

SCHOTTKY BARRIER RECTIFIERS

15 AMPERES
20, 30, 40 VOLTS



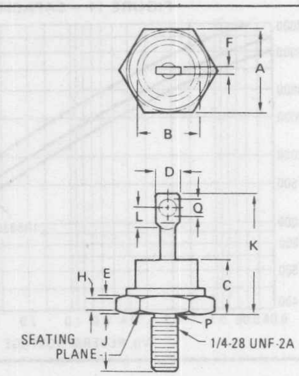
HOT CARRIER POWER RECTIFIER

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.96	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

*MAXIMUM RATINGS

Rating	Symbol	1N5832	1N5833	1N5834	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	Volts
Average Rectified Forward Current $V_{R(equiv)} \leq 0.2\ V_{R(dc)}, T_C = 75^oC$	I_O	← 40 →			Amp
Ambient Temperature Rated $V_{R(dc)}$, $P_{F(AV)} = 0$, $R_{\theta JA} = 2.0^oC/W$	T_A	100	95	90	^oC
Non-Repetitive Peak Surge Current (surge applied at rated load conditions halfwave, single phase, 60 Hz)	I_{FSM}	← 800 (for 1 cycle) →			Amp
Operating and Storage Junction Temperature Range (Reverse voltage applied)	T_J, T_{stg}	← -65 to +125 →			^oC
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	← 150 →			^oC

*THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.0	$^oC/W$

*ELECTRICAL CHARACTERISTICS ($T_C = 25^oC$ unless otherwise noted.)

Characteristic	Symbol	1N5832	1N5833	1N5834	Unit
Maximum Instantaneous Forward Voltage(1)	v_F				Volts
(i_F = 10 Amp)		0.360	0.370	0.380	
(i_F = 40 Amp)		0.520	0.550	0.590	
(i_F = 125 Amp)		0.980	1.080	1.180	
Maximum Instantaneous Reverse Current @ rated dc Voltage (1)	i_R				mA
		20	20	20	
$T_C = 100^oC$		150	150	150	

*Indicates JEDEC Registered Data.

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and terminal lead is readily solderable.

POLARITY: Cathode to Case

MOUNTING POSITION: Any

STUD TORQUE: 25 in. lb. Max

SOLDER HEAT: See Note 3

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}\,P_{F(AV)} - R_{\theta JA}\,P_{R(AV)} \qquad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JC}$ = Junction-to-ambient thermal resistance

Figures 1, 2 and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA}\,P_{R(AV)} \qquad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}\,P_{F(AV)} \qquad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2 and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2 and 3 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \qquad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for 1N5834 operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 30 A ($I_{F(AV)}$ = 15 A), $I_{(PK)}/I_{(AV)}$ = 10, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 3°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴
$V_{R(equiv)}$ = (10)(1.41)(0.65) = 9.18 V

Step 2: Find T_R from Figure 3. Read T_R = 118°C @ V_R = 9.18 V & $R_{\theta JA}$ = 3°C/W

Step 3: Find $P_{F(AV)}$ from Figure 4.†Read $P_{F(AV)}$ = 20 W @ $\frac{I_{(PK)}}{I_{(AV)}}$ = 10 & $I_{F(AV)}$ = 15 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 118-(3)(20) = 58°C

†Values given are for the 1N5834. Power is slightly lower for the other units because of their lower forward voltage.

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped (1),(2)	
Load	Resistive	Capacitive (1)	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

(1) Note that $V_{R(PK)} \approx 2\,V_{in(PK)}$

(2) Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE – 1N5832

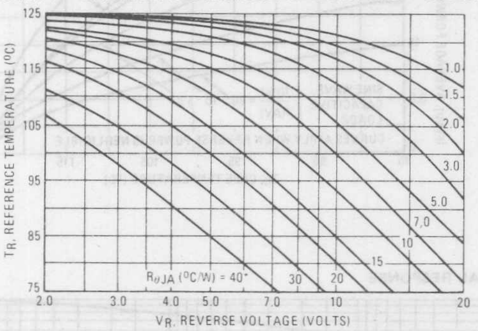


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE – 1N5833

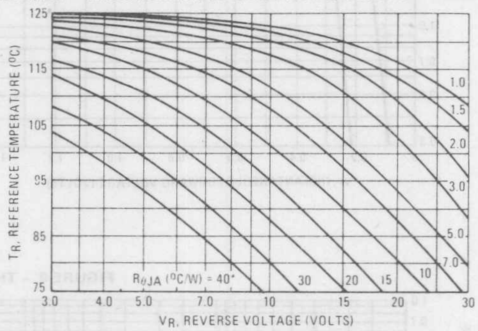


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE – 1N5834

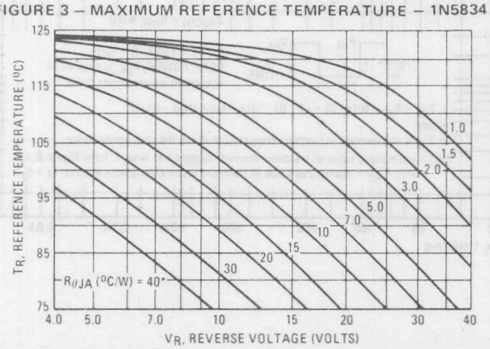
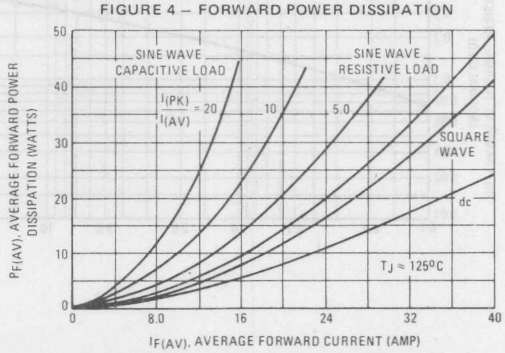


FIGURE 4 – FORWARD POWER DISSIPATION



*No external heat sink.

FIGURE 5 — TYPICAL FORWARD VOLTAGE

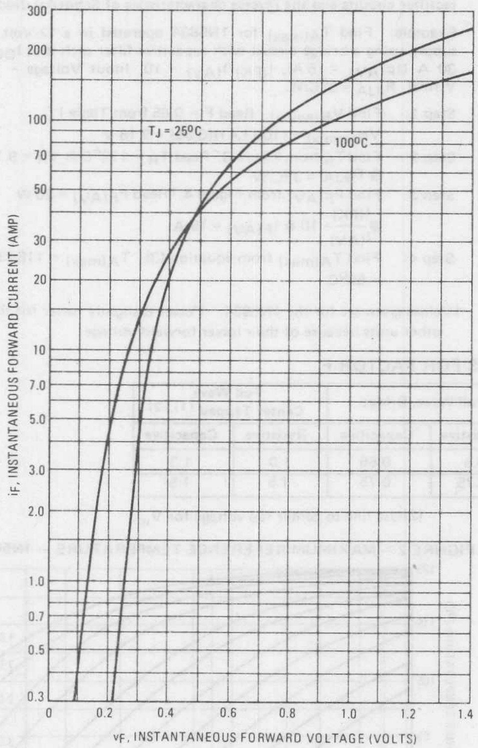


FIGURE 6 — MAXIMUM SURGE CAPABILITY

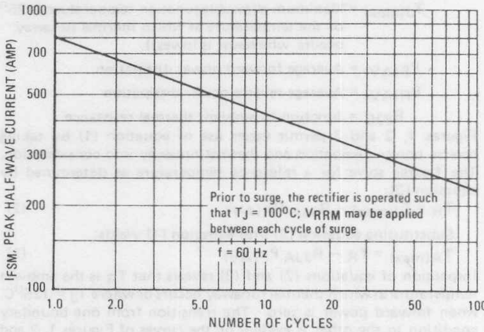


FIGURE 7 — CURRENT DERATING

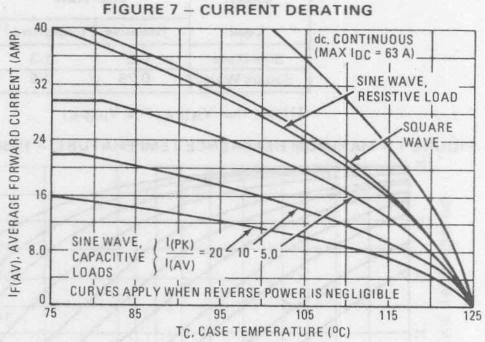


FIGURE 8 — THERMAL RESPONSE

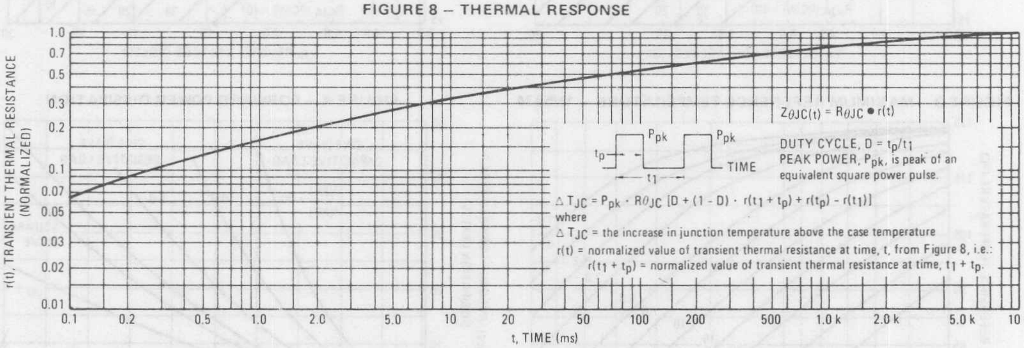


FIGURE 9 – NORMALIZED REVERSE CURRENT

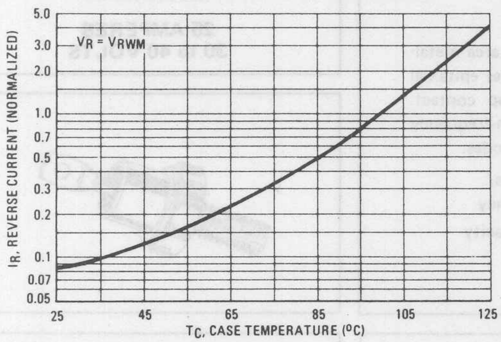


FIGURE 10 – TYPICAL REVERSE CURRENT

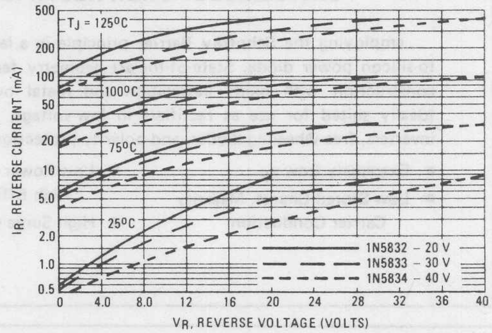
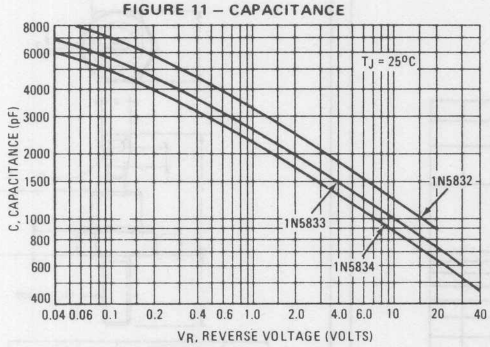


FIGURE 11 – CAPACITANCE



NOTE 2: HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 11).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

NOTE 3: SOLDER HEAT

The excellent heat transfer property of the heavy duty copper anode terminal which transmits heat away from the die requires that caution be used when attaching wires. Motorola suggests a heat sink be clamped between the eyelet and the body during any soldering operation.

MOTOROLA

1N6095
1N6096

SWITCHMODE POWER RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free-wheeling diodes, and polarity-protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity

SCHOTTKY BARRIER RECTIFIERS

25 AMPERES
30 to 40 VOLTS

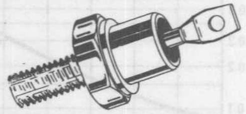
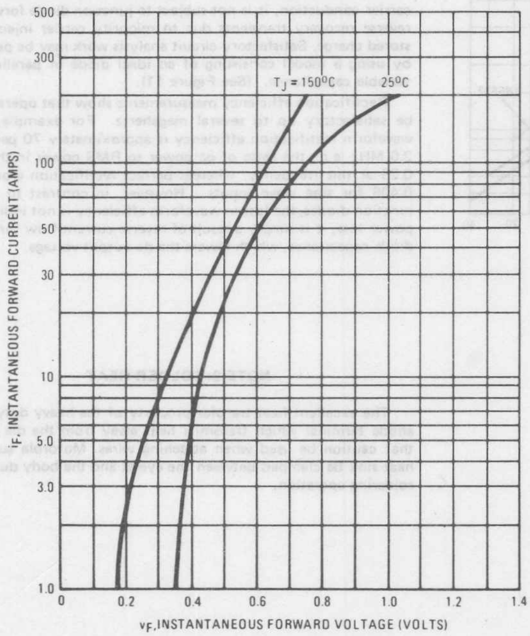
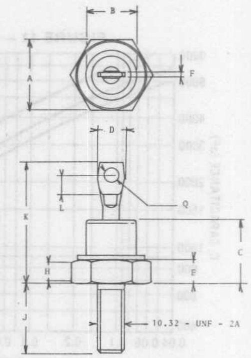


FIGURE 1 – TYPICAL FORWARD VOLTAGE





DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.025	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56
DO-4

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion-resistant and terminal leads are readily solderable.

POLARITY: Cathode to case

MOUNTING POSITIONS: Any

STUD TORQUE: 15 in. lb. max

1N6095, 1N6096

MAXIMUM RATINGS

Rating	Symbol	1N6095*	1N6096*	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	30	40	Volts
Average Rectified Forward Current (Rated V_R)	I_O	25 $T_C = 70°C$	25 $T_C = 70°C$	Amp
Case Temperature (Rated V_R)	T_C	105	105	°C
Non-repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	400	400	Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +125	−65 to +125	°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	150	150	°C
Voltage Rate of Change (Rated V_R)	dv/dt	—	—	v/μs

THERMAL CHARACTERISTICS

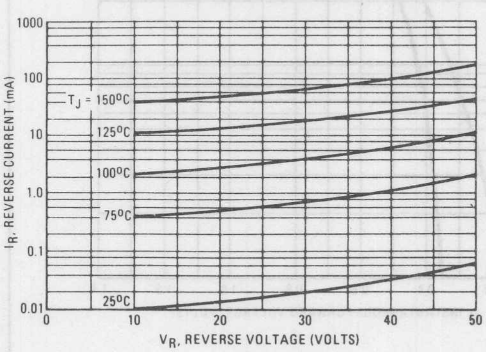
Characteristic	Symbol	1N6095*	1N6096*	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	← 2.0 →		°C/W

ELECTRICAL CHARACTERISTICS ($T_C = 25°C$ unless otherwise noted)

Characteristic	Symbol	1N6095*	1N6096*	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 78.5 Amp, T_C = 70°C)	v_F	— 0.86 —	— 0.86 —	Volts
Maximum Instantaneous Reverse Current (1) (Rated dc Voltage, T_C = 125°C)	i_R	250	250	mA
Capacitance (V_R = 1.0 Vdc, 100 kHz ≥ f ≥ 1.0 MHz)	C_t	6000	6000	pF

*Indicates JEDEC registered data
(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

FIGURE 2 — TYPICAL REVERSE CURRENT



MOTOROLA

1N6097
1N6098

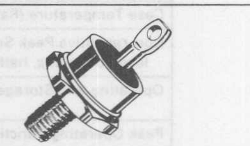
SWITCHMODE POWER RECTIFIERS

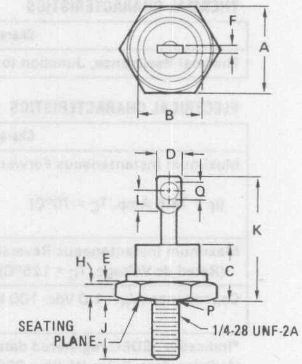
. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free-wheeling diodes, and polarity-protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/ High Efficiency
- High Surge Capacity

SCHOTTKY BARRIER RECTIFIERS

50 AMPERES
30 and 40 VOLTS



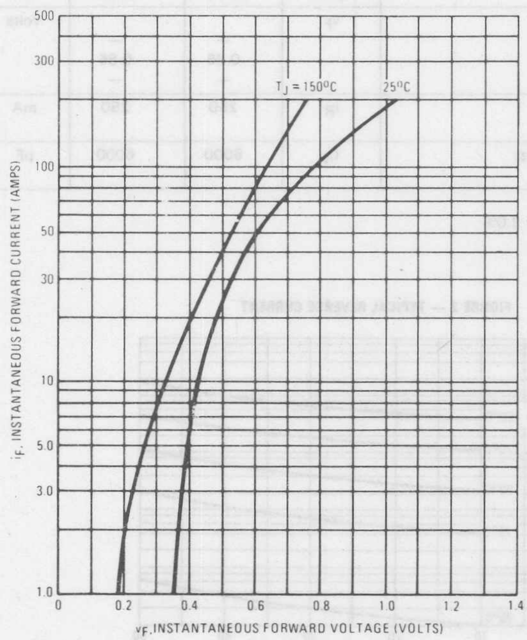


DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.86	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

FIGURE 1 – TYPICAL FORWARD VOLTAGE



MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion-resistant and terminal lead is readily solderable.

POLARITY: Cathode to case

MOUNTING POSITIONS: Any

STUD TORQUE: 25 in. lb. max

***MAXIMUM RATINGS**

Rating	Symbol	1N6097	1N6098	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	30	40	Volts
Average Rectified Forward Current (Rated V_R)	I_O	50 $T_C = 70°C$	50 $T_C = 70°C$	Amp
Case Temperature (Rated V_R)	T_C	115	115	°C
Non-repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	← 800 →		Amp
Operating and Storage Junction Temperature Range (Reverse Voltage Applied)	T_J, T_{stg}	−65 to +125	−65 to +125	°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	150	150	°C

***THERMAL CHARACTERISTICS**

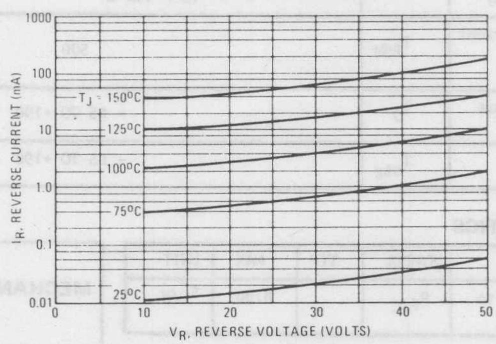
Characteristic	Symbol	1N6097	1N6098	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	← 1.0 →		°C/W

***ELECTRICAL CHARACTERISTICS** ($T_C = 25°C$ unless otherwise noted)

Characteristic	Symbol	1N6097	1N6098	Unit
Maximum Instantaneous Forward Voltage (1) ($i_F = 157$ Amp, $T_C = 70°C$)	v_F	0.86	0.86	Volts
Maximum Instantaneous Reverse Current (1) (Rated dc Voltage, $T_C = 125°C$)	i_R	250	250	mA
Capacitance ($V_R = 1.0$ Vdc, 100 kHz ≤ f ≤ 1.0 MHz)	C_t	7000	7000	pF

*Indicates JEDEC registered data
(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

FIGURE 2 — TYPICAL REVERSE CURRENT



![Motorola logo] **MOTOROLA**

40 HF, HFM SERIES
41 HF, HFM SERIES

STUD MOUNTED POWER RECTIFIER

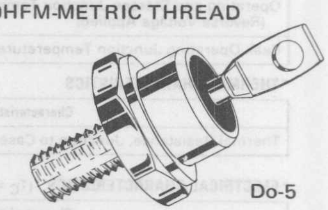
. . . compact, highly efficient silicon rectifier for medium current applications requiring:

— High Current Surge —500 Amperes
— Peak performance at elevated temperatures

STANDARD RECOVERY POWER RECTIFIER

100—1600 V
40 AMPERES

40HF SERIES-UNF THREAD
40HFM-METRIC THREAD



Do-5

Designers Data for „Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics — are given to facilitate „worst case" design.

MAXIMUM RATINGS

RATING	SYMBOL	40HF10	40HF20	40HF40	40HF60	40HF80	40HF100	40HF120	40HF140	40HF160	UNITS
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	100	200	400	600	800	1000	1200	1400	1600	VOLTS
Non-Repetitive Peak Reverse Voltage	V_{RSM}	150	275	500	725	950	1250	1450	1650	1900	VOLTS
RMS Reverse Voltage	$V_{R(RMS)}$	70	140	280	420	560	700	840	980	1120	VOLTS
Average Rectifier Forward Current (Single phase, Resistive load)	I_O	40A Tc = 140°C						40A Tc = 110°C			AMPS
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	500									AMPS
Operating Junction Temperature Range	T_J	- 65 TO +190									°C
Storage Temperature Range	T_{stg}	- 65 TO +190									°C

THERMAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	TYP	MAX	UNIT
Thermal Resistance, Junction to Case	$R_{\theta JC}$		0.90	°C/W

ELECTRICAL CHARATERISTICS

CHARACTERISTIC	SYMBOL	MAX	UNIT
Instantaneous Forward Voltage (I_F = 63amp, T_J = 150°C)	V_F	1.15	Volts
Reverse Current (rated dc voltage T_C = 25°C T_C = 100°C	I_R	100 500	μA

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed.
FINISH: All external surfaces corrosion resistant & readly solderable.
POLARITY: Cathode to Case.
WEIGHT: 17 Grams (Approximately)
MOUNTING TORQUE: 25 in-1bs max.
41HF, HFM SERIES IS IDENTICAL TO 40HF, HFM WITH FLEXIBLE LEAD.

FIGURE 1 – FORWARD VOLTAGE

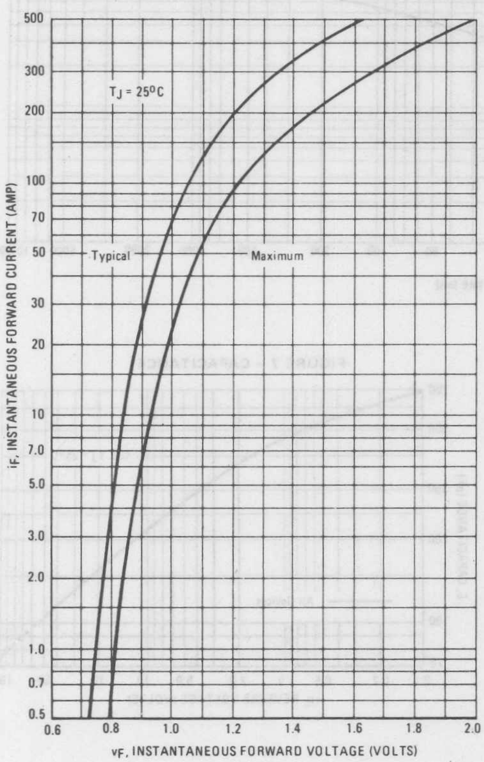


FIGURE 2 – MAXIMUM SURGE CAPABILITY

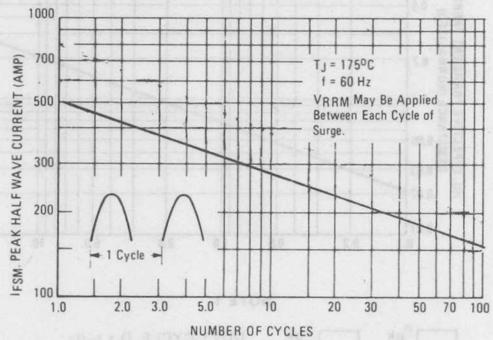


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

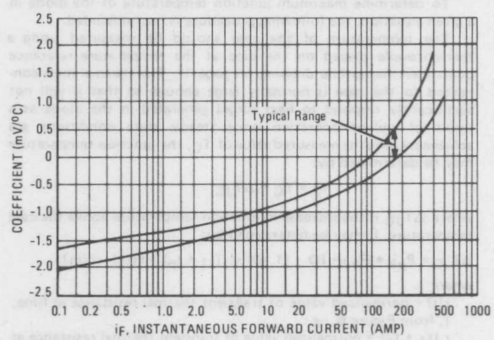


FIGURE 4 – CURRENT DERATING

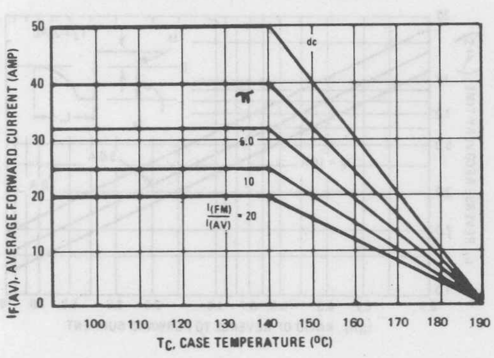


FIGURE 5 – FORWARD POWER DISSIPATION

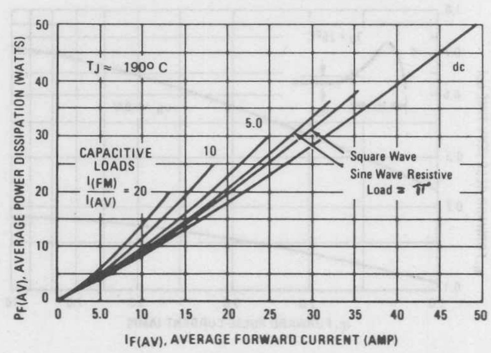
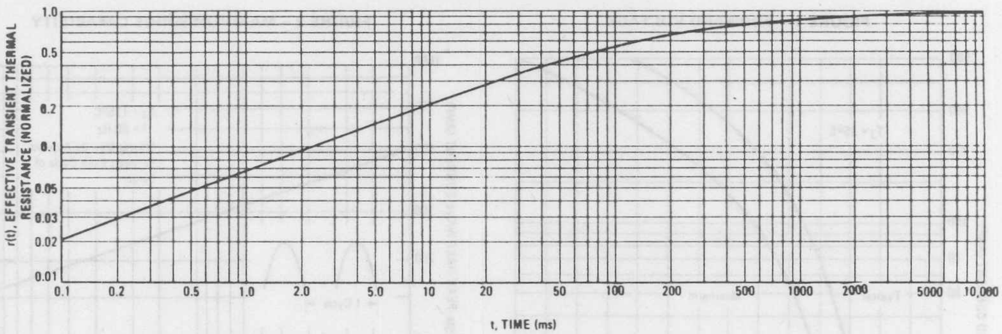
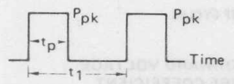


FIGURE 6 – THERMAL RESPONSE



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC}\,[D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

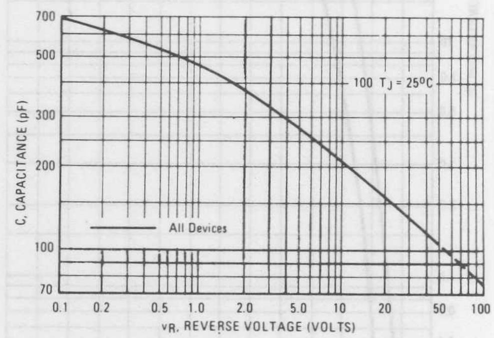


FIGURE 8 – FORWARD RECOVERY TIME

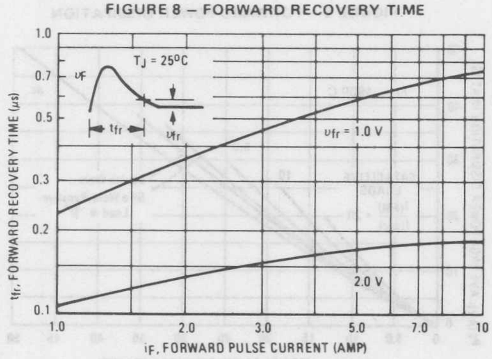


FIGURE 9 – REVERSE RECOVERY TIME

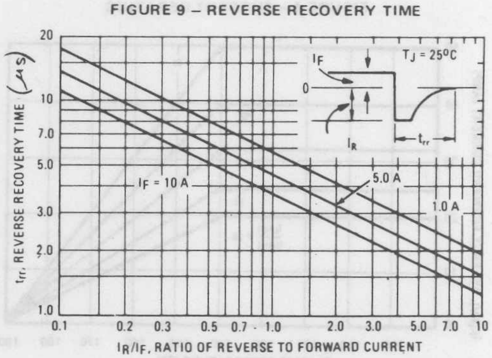
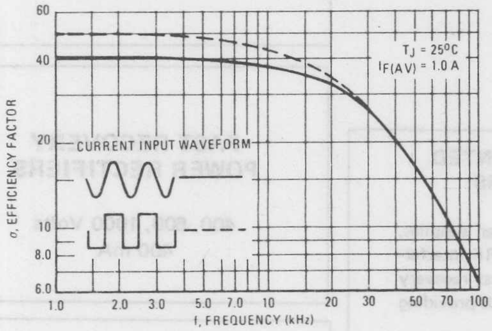
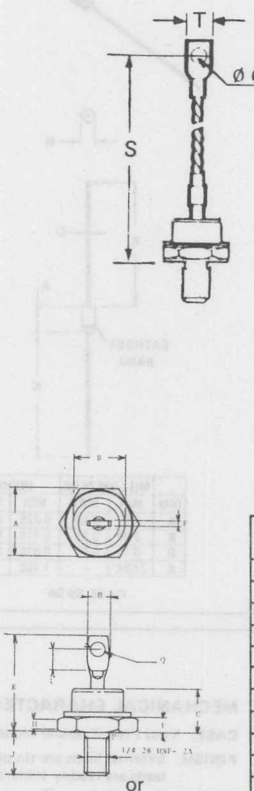


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY





or

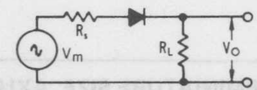
ISO M6

Case 257-01

DIM	MILLIMETERS		INCHES	
	min.	max	min	max
A	16.94	17.45	0.667	0.687
B	-	16 94	-	0.667
C	-	11.43	-	0.450
D	-	9.53	-	0.375
E	2.92	5.08	0.115	0.200
F	-	2.03	-	0.080
H	1.52	-	0.060	-
J	10.72	11.51	0.422	0.453
K	-	25.40	-	1.000
L	3.86	-	0.152	-
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175
S	75.0	–	1.90	-
T	6.0	–	0.235	-
U	3.50	4.50	0.135	0.180

NOTE 2 – RECTIFICATION EFFICIENCY

FIGURE 11 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\dfrac{V^2_{O(dc)}}{R_L}}{\dfrac{V^2_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2_{O(dc)}}{V^2_{O(ac)} + V^2_{O(dc)}} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assumed lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\dfrac{V^2_m}{\pi^2 R_L}}{\dfrac{V^2_m}{4R_L}} \bullet 100\% = \frac{4}{\pi^2} \bullet 100\% = 40.6\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\dfrac{V^2_m}{2R_L}}{\dfrac{V^2_m}{R_L}} \bullet 100\% = 50\% \quad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby red· the value of the efficiency factor σ, as shown on Figure 10.

It should be emphasized that **Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses.** Data was obtained by measuring the ac component of V_O with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

REVERSE POLARITY
anode to case available,
add R to type number,
example 40 HFR 10

MOTOROLA

BA 157 SERIES

FAST RECOVERY POWER RECTIFIERS

400, 600, 1000 Volts
400 mA

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

. . . designed for special application such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 300 nanoseconds providing high efficiency at frequencies to 250 Hz.

DESIGNER'S DATA FOR „WORST CASE" CONDITIONS

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves – representing device characteristic boundaries – are given to facilitate „worst case" design.

MAXIMUM RATINGS

Ratings	Symbol	BA 157	BA 158	BA 159	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RWM} V_{RRM} V_R	400	600	1000	Volts
Non Repetitive Peak Reverse Voltage	V_{RSM}	500	800	1200	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	280	420	700	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_A = 75^o$ C)	I_O	← 400 →			mA
Non-Repetitive Peak Surge Current (surge applied at rated load conditions) ($T_A = 75^o$ C)	I_{FSM}	← 15 →			Amps
Operating Junction Temp. Range	T_J	← -65 to +150 →			^{o}C
Storage Temperature Range	T_{stg}	← -65 to +175 →			^{o}C

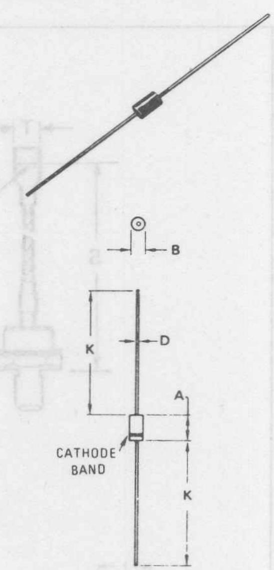
THERMAL CHARACTERISTICS

Characteristics	Symbol	Max.	Unit
Thermal Resistance, Junction to Ambient (Typical Primted Circuit Board Mounting)	$R_{\theta JA}$	65	^{o}C/W

Characteristics	Symbol	Min	Typ	Max	Unit
Forward Voltage (I_F = 1,0 Amp. T_A = 25 Grad C)	V_F	—	1,0	1,25	Volts
Reverse Current (rated dc voltage) $T_A = 25^o$ C $T_A = 100^o$ C	I_R	— —	1,0 5,0	5 100	μA

REVERSE RECOVERY CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time I_F = 10 mA to I_R = 10 mA, 1 mA	t_{rr}	—	—	500	ns



	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	-	1.100	-

CASE 59-04

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded

FINISH: External leads are tin plated, leads are readily solderable

POLARITY: Cathode indicated by Polarity band

WEIGHT: 0.4 Grams (Approximately)

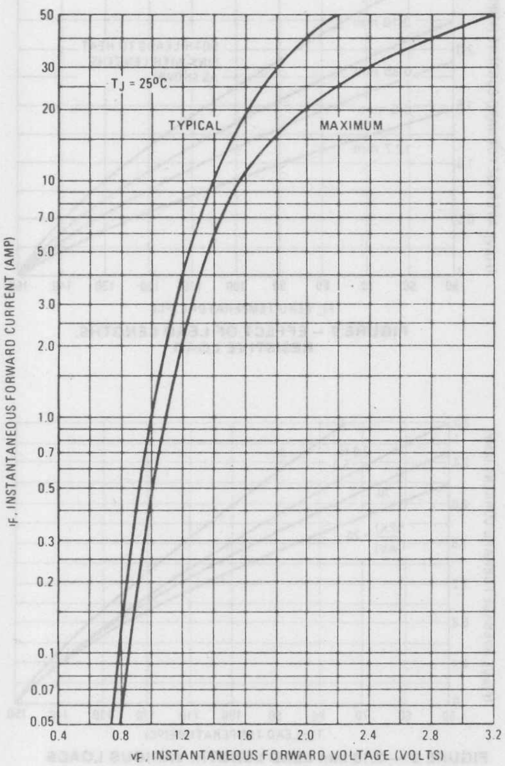


FIGURE 1 – FORWARD VOLTAGE

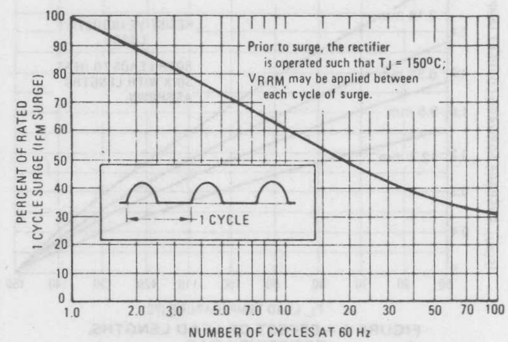


FIGURE 2 – MAXIMUM SURGE CAPABILITY

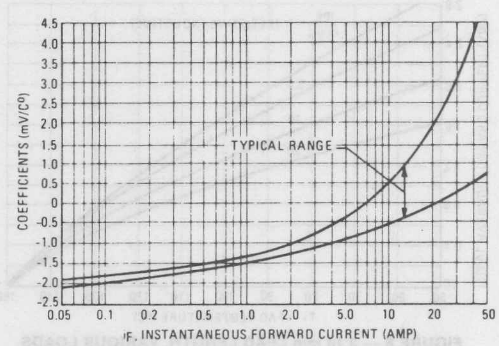


FIGURE 3 – TEMPERATURE COEFFICIENT

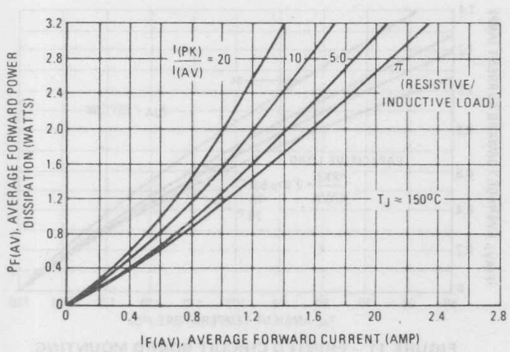


FIGURE 4 – FORWARD POWER DISSIPATION

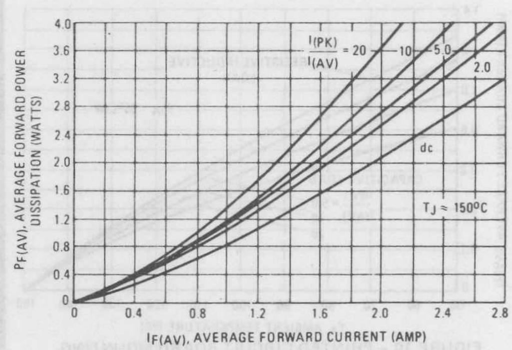


FIGURE 5 – FORWARD POWER DISSIPATION

MAXIMUM CURRENT RATINGS
(SEE NOTES 1 and 2)

SINE WAVE INPUT

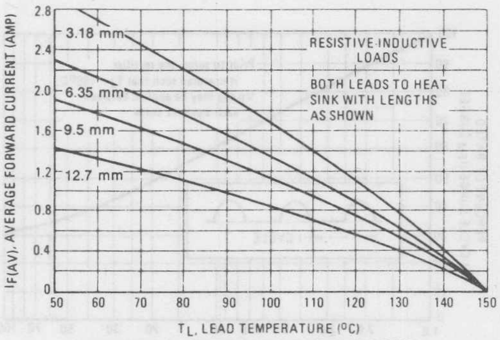


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

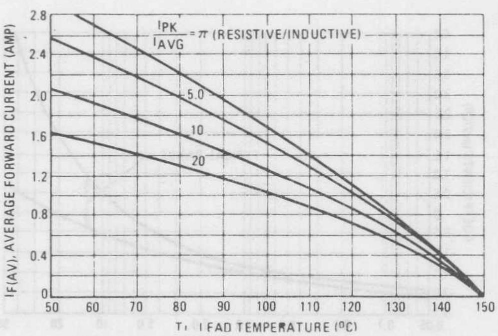


FIGURE 8 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

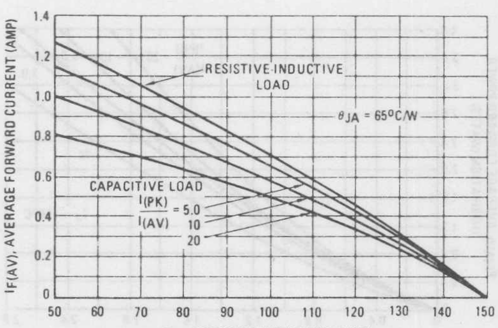


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

SQUARE WAVE INPUT

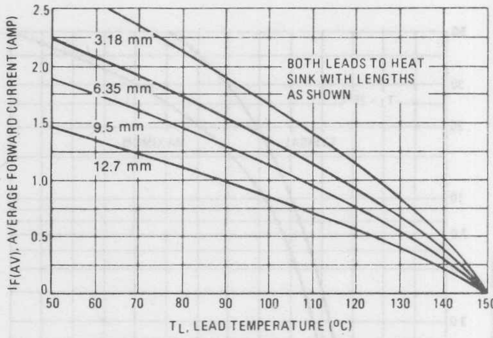


FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

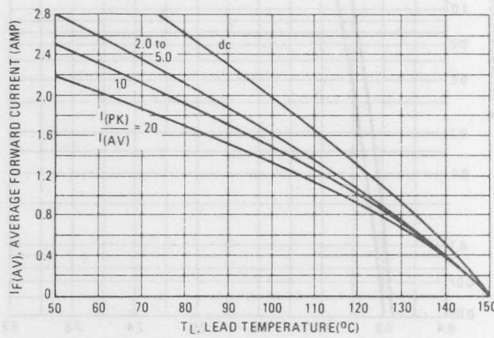


FIGURE 9 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

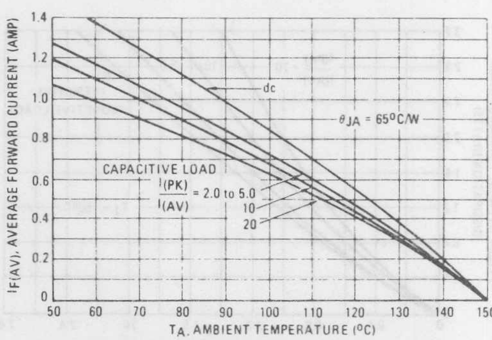


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

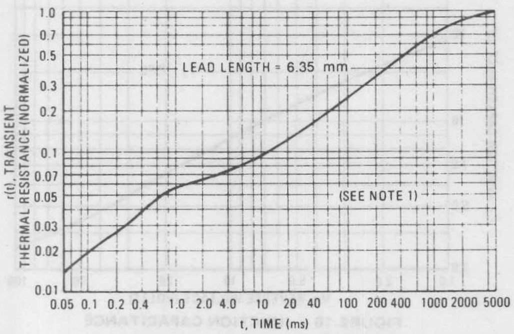


FIGURE 12 – THERMAL RESPONSE

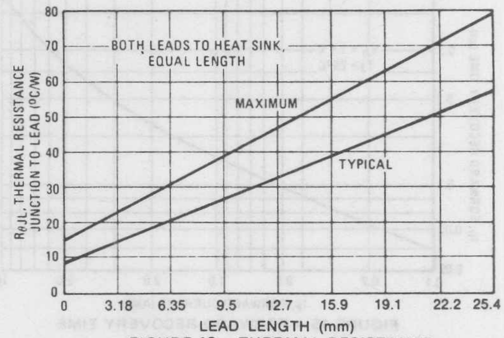
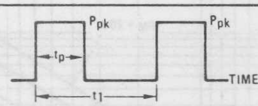


FIGURE 13 – THERMAL RESISTANCE

NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC}\left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)\right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 12, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

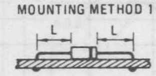
NOTE 2

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

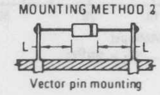
TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L(mm)				
	3.81	6.35	12.7	19.1	$R_{\theta JA}$
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W

MOUNTING METHOD 1



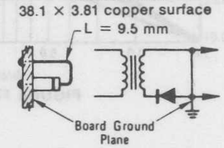
MOUNTING METHOD 2

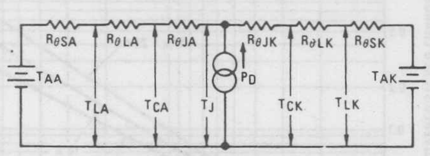


Vector pin mounting

MOUNTING METHOD 3

P. C. Board with
38.1 × 3.81 copper surface





Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.)

Values for thermal resistance components are:

$R_{\theta L}$ = 112°C/W/IN. Typically and 128°C/W/IN Maximum
$R_{\theta J}$ = 18°C/W Typically and 30°C/W Maximum

The maximum lead temperature may be calculated as follows:

$$T_L = 150^{\circ} - \Delta T_{JL}$$

ΔT_{JL} can be calculated as shown in NOTE 1 or it may be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \bullet P_F$; P_F may be formulated for sine-wave operation from Figure 3 or from Figure 4 for square-wave operation.

FIGURE 14 – THERMAL CIRCUIT MODEL

TYPICAL DYNAMIC CHARACTERISTICS

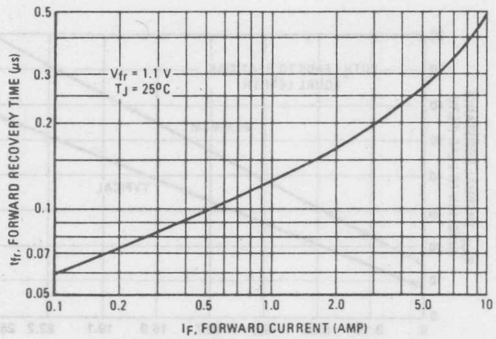


FIGURE 15 – FORWARD RECOVERY TIME

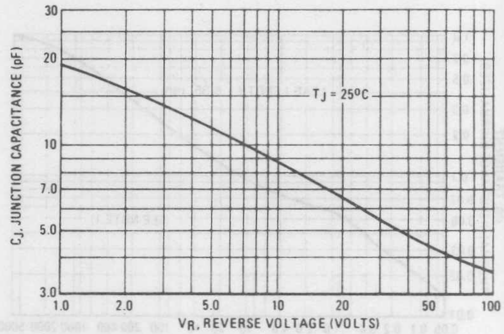


FIGURE 16 – JUNCTION CAPACITANCE

TYPICAL RECOVERED STORED CHARGE DATA
(SEE NOTE 3)

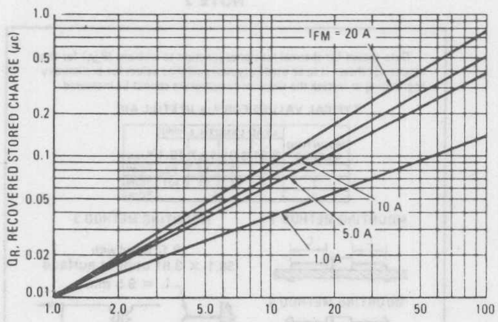


FIGURE 17 – T_J = 25°C

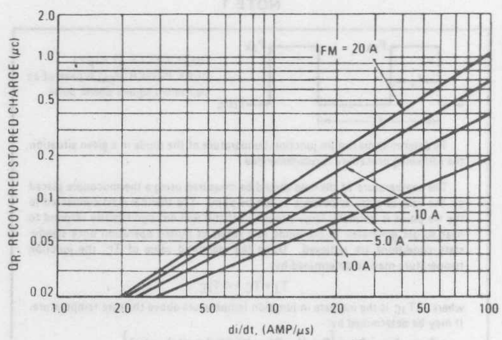


FIGURE 18 – T_J = 75°C

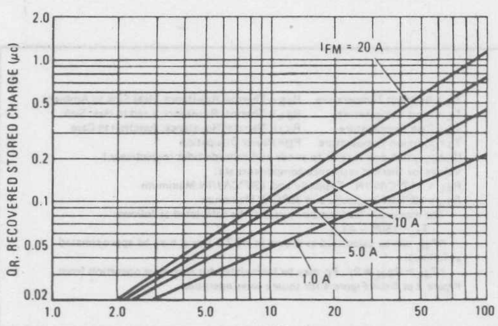


FIGURE 19 – T_J = 100°C

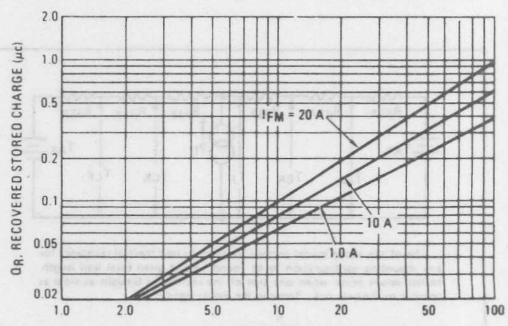


FIGURE 20 – T_J = 150°C

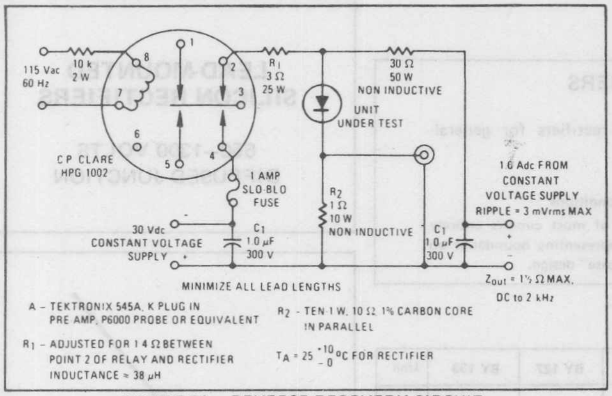


FIGURE 21 – REVERSE RECOVERY CIRCUIT

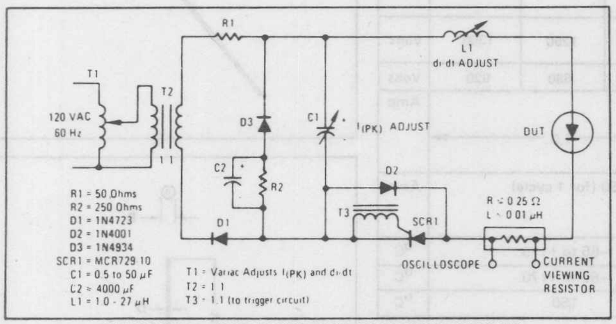


FIGURE 22 – JEDEC REVERSE RECOVERY CIRCUIT

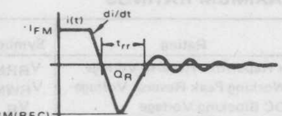
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

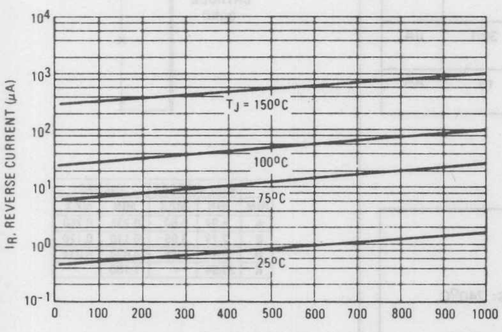


FIGURE 23 – TYPICAL REVERSE LEAKAGE

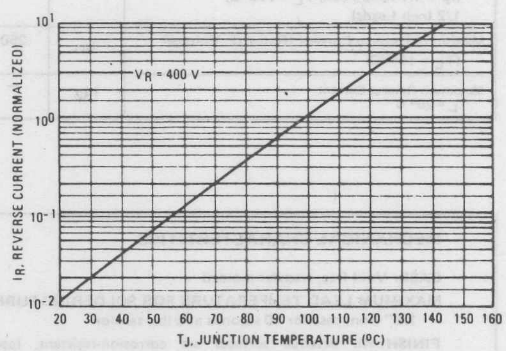


FIGURE 24 – TYPICAL REVERSE LEAKAGE

MOTOROLA

BY 126, 127, BY 133 SERIES

"SURMETIC" RECTIFIERS

. . . subminiature size, axial lead-mounted rectifiers for general-purpose, low-power applications.

Designers Data for "Worst Case" Conditions

The Designers Data Sheets permit the design of most circuits entirely from the information presented. Limits curves—representing boundaries on device characteristics—are given to facilitate "worst-case" design.

LEAD-MOUNTED SILICON RECTIFIERS

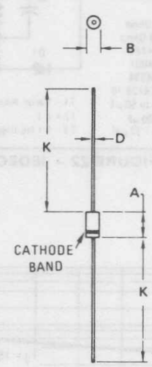
650–1300 VOLTS
DIFFUSED JUNCTION

MAXIMUM RATINGS

Rating	Symbol	BY 126	BY 127	BY 133	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	650	1250	1300	Volts
Nonrepetitive Peak Reverse Voltage (Halfwave, Single Phase, 60 Hz)	V_{RSM}	650	1250	1300	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	460	880	920	Volts
Average Rectified Forward Current (Single Phase, Resistive Load, 60 Hz, $T_L = 70^oC$, 1/2" From Body)	I_O	← 1,0 →			Amp
Nonrepetitive Peak Surge Current (Surge Applied at Rated Load Conditions, See Figure 2)	I_{FSM}	50 (for 1 cycle)			Amp
Storage Temperature Range	T_{stg}	-65 to +175			^oC
Operating Temperature Range	T_L	-65 to +170			^oC
DC Blocking Voltage Temperature	T_L	150			^oC

ELECTRICAL CHARACTERISTICS

Characteristic and Conditions	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop (i_F = 4.7 Amp Peak, $T_L = 170^oC$, 1/2 Inch Leads)	v_F	–	1.4	Volts
Maximum Reverse Current (Rated dc Voltage) ($T_L = 150^oC$)	I_{R1}	250	300	µA
Maximum Reverse Current $T_L = 25^o$ C	I_{R2}	–	10	µA



	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

CASE 59-04

Dimensions Within JEDEC DO-15 Outline.

MECHANICAL CHARACTERISTICS

CASE: Void free, transfer molded

MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 240°C, 1/8" from case for 10 seconds at 5 lbs. tension

FINISH: All external surfaces are corrosion-resistant, leads are readily solderable

POLARITY: Cathode indicated by color band

WEIGHT: 0.40 grams (approximately)

FIGURE 1 – FORWARD VOLTAGE

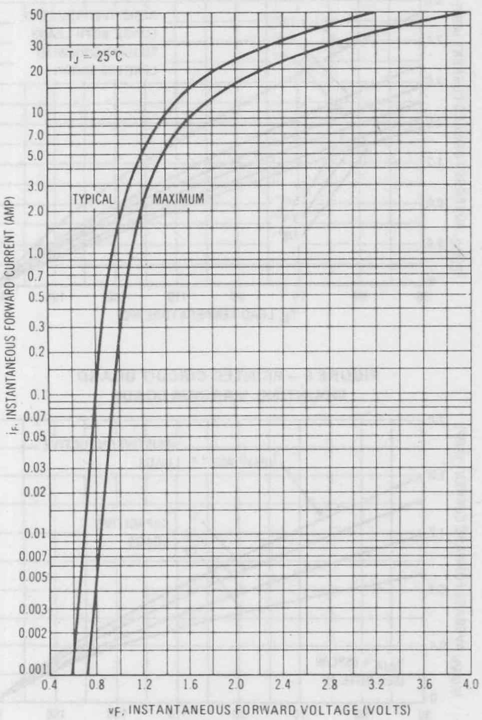


FIGURE 2 – MAXIMUM NONREPETITIVE SURGE CURRENT

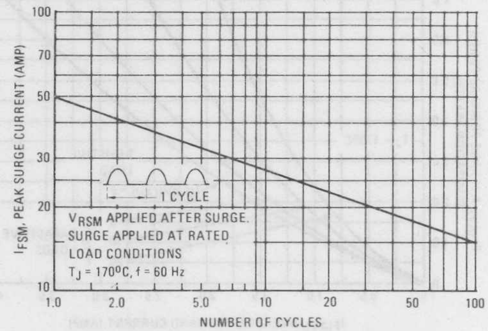


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

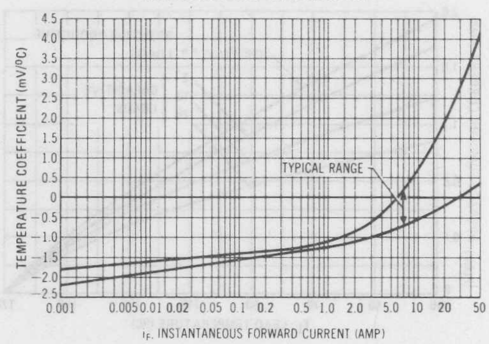
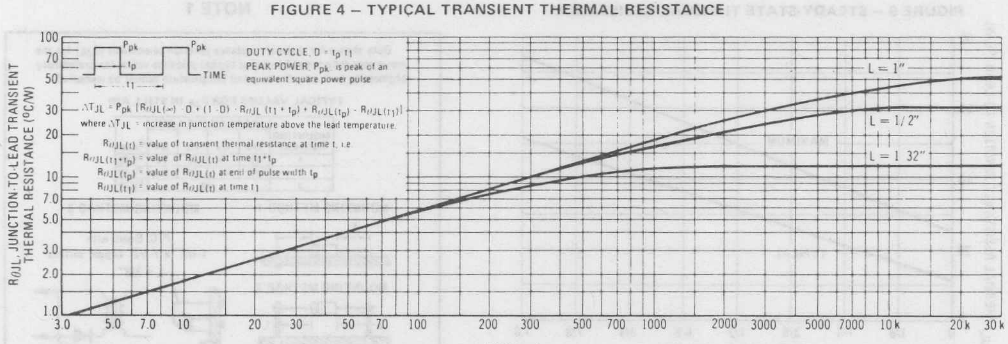


FIGURE 4 – TYPICAL TRANSIENT THERMAL RESISTANCE



The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

$$T_J = T_L + \triangle T_{JL}.$$

FIGURE 5 – FORWARD POWER DISSIPATION

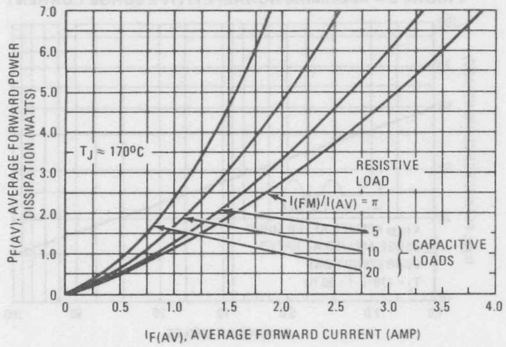


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

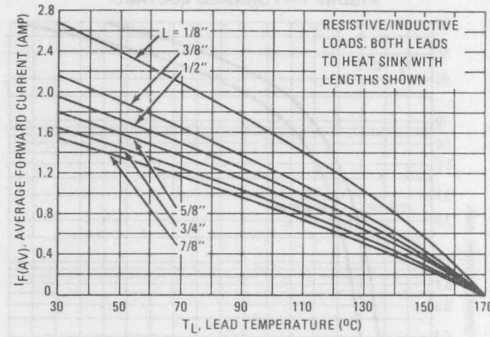


FIGURE 7 – 1/2" LEAD LENGTH, VARIOUS LOADS

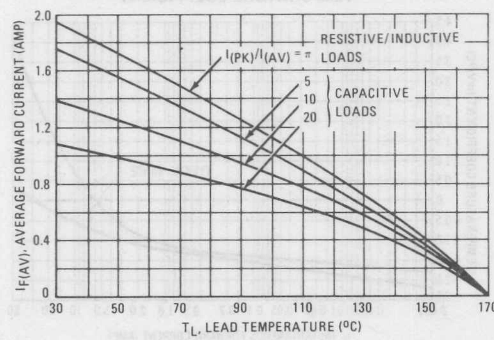


FIGURE 8 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

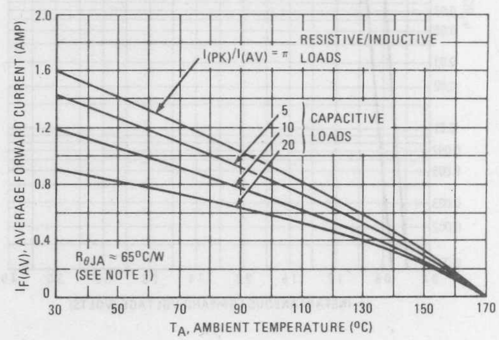
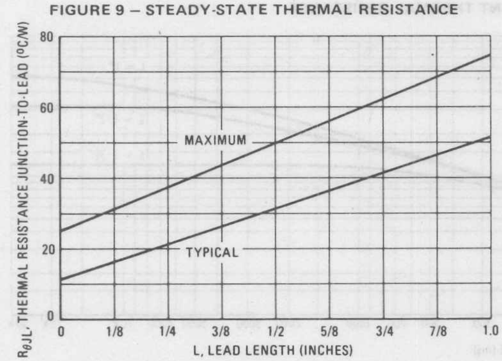


FIGURE 9 – STEADY-STATE THERMAL RESISTANCE



NOTE 1

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN) 1/8	1/4	1/2	3/4	$R_{\theta JA}$
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W

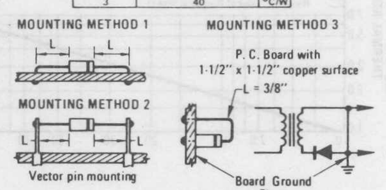


FIGURE 10 – FORWARD RECOVERY TIME

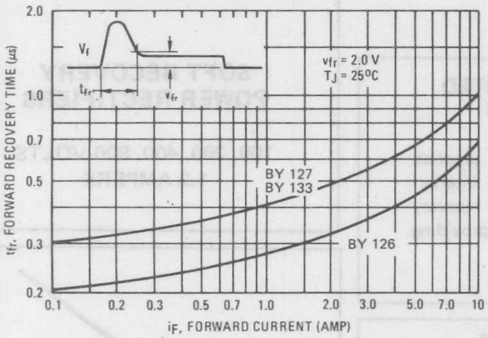


FIGURE 11 – REVERSE RECOVERY TIME

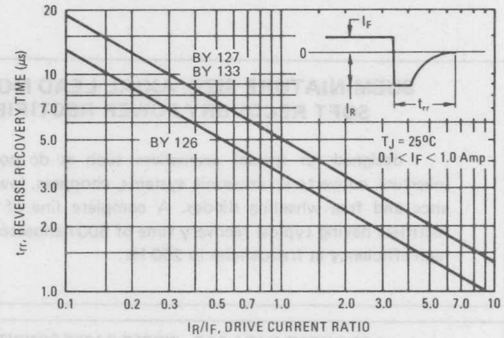


FIGURE 12 – JUNCTION CAPACITANCE

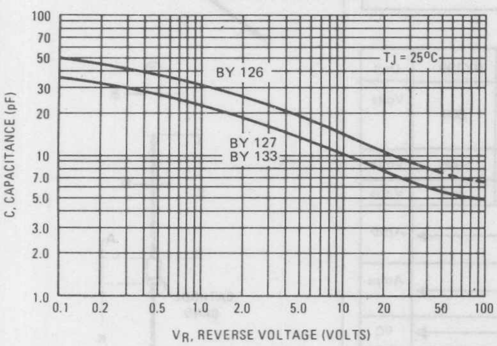


FIGURE 13 – RECTIFICATION WAVEFORM EFFICIENCY FOR SINE WAVE

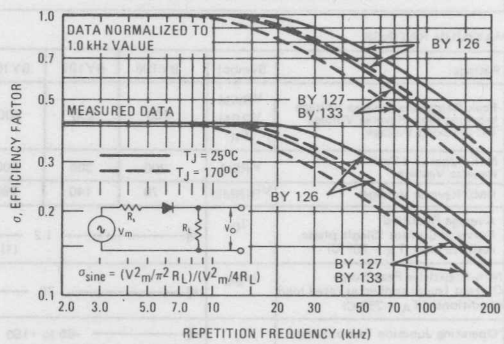
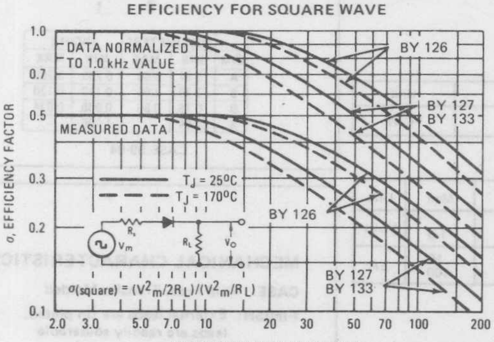


FIGURE 14 – RECTIFICATION WAVEFORM EFFICIENCY FOR SQUARE WAVE



RECTIFIER EFFICIENCY NOTE

The rectification efficiency factor σ shown in Figures 13 and 14 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\frac{V^2_{O(dc)}}{R_L}}{\frac{V^2_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2_{O(dc)}}{V^2_{O(ac)} + V^2_{O(dc)}} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assumed lossless, the maximum theoretical efficiency factor becomes 40%; for a square wave input of amplitude V_m, the efficiency factor becomes 50%. (A full wave circuit has twice these efficiencies).

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 11) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current thereby reducing the value of the efficiency factor σ, as shown in Figures 13 and 14.

It should be emphasized that Figures 13 and 14 show waveform efficiency only; they do not account for diode losses. Data was obtained by measuring the ac component of V_O with a true rms voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for the Figures.

MOTOROLA

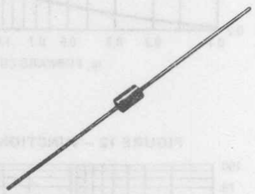
BY 196 SERIES

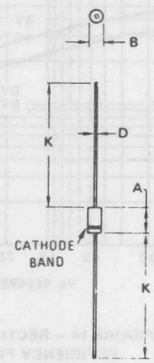
SUBMINIATURE SIZE, AXIAL LEAD MOUNTED SOFT RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 500 nanoseconds providing high efficiency at frequencies to 250 Hz.

SOFT RECOVERY POWER RECTIFIERS

100, 200, 400, 800 VOLTS
1.2 AMPERE





	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	-	1.100	-

CASE 59-04

DESIGNER'S DATA FOR „WORST CASE" CONDITIONS

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves – representing device characteristic boundaries – are given to facilitate „worst case" design.

MAXIMUM RATINGS

Ratings	Symbol	BY196	BY197	BY198	BY199	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RWM} V_{RRM} V_R	100	200	400	800	Volts
Non Repetitive Peak Reverse Voltage	V_{RSM}	200	300	500	1000	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	70	140	280	560	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_A = 75^o$ C)	I_O	←	1.2 (1)		→	Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions) ($T_A = 25^o$ C)	I_{FSM}	←	70		→	Amps
Operating Junction Temp. Range	T_J	←	−65 to +150		→	^{o}C
Storage Temperature Range	T_{stg}	←	−65 to +175		→	^{o}C

I. Valid with leads at ambient Temperature at a Distance of 10 mm from case

THERMAL CHARACTERISTICS

Characteristics	Symbol	Max.	Unit
Thermal Resistance, Junction to Ambient (Typical Printed Circuit Board Mounting)	$R_{\theta JA}$	65	^{o}C/W

ELECTICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Forward Voltage (I_F = 3,0 Amp. T_A = 25 ^{o}C)	V_F	—	1.1	1.3	Volts
Reverse Current (rated dc voltage) T_A = 25^o C T_A = 100^o C	I_R	— —	1.0 50	10 100	μA

REVERSE RECOVERY CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time I_F = 10 mA through I_R = 10 mA to I_R = 1 mA	t_{rr}	—	—	500	ns
I_F = 1 Amp. to V_R = 30 V_{DC} (figure 21)	t_{rr}	—	350	750	ns

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded

FINISH: External leads are tin plated, leads are readily solderable

POLARITY: Cathode indicated by Polarity band

WEIGHT: 0.4 Grams (Approximately)

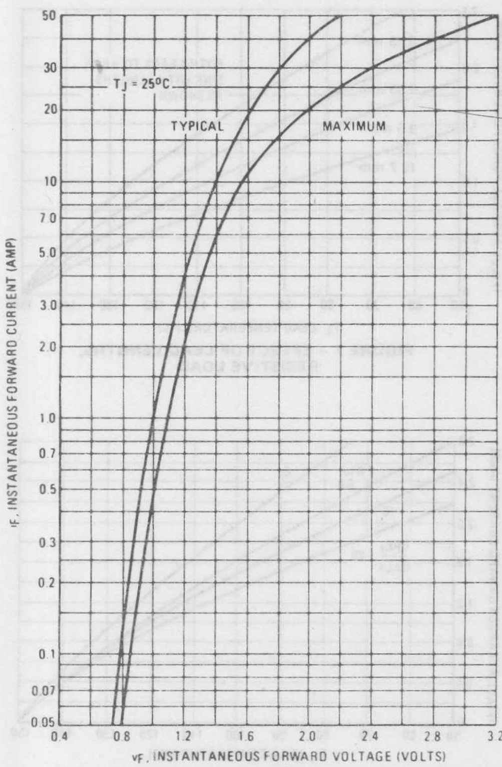


FIGURE 1 – FORWARD VOLTAGE

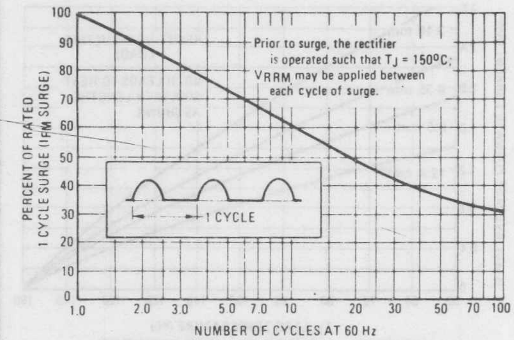


FIGURE 2 – MAXIMUM SURGE CAPABILITY

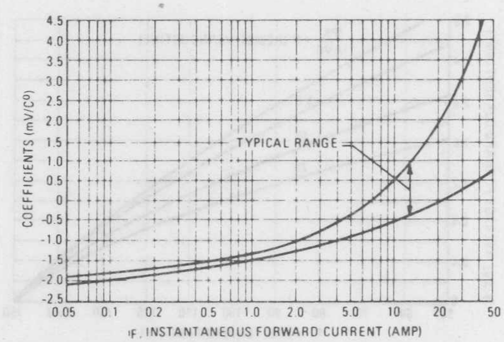


FIGURE 3 – TEMPERATURE COEFFICIENT

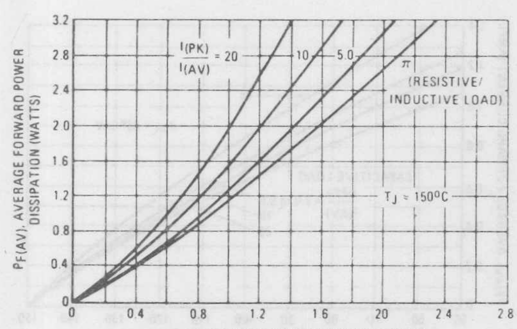


FIGURE 4 – FORWARD POWER DISSIPATION

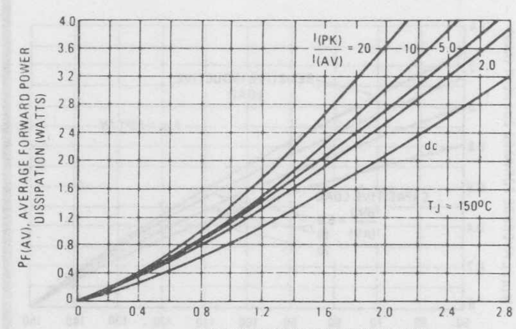


FIGURE 5 – FORWARD POWER DISSIPATION

MAXIMUM CURRENT RATINGS
(SEE NOTES 1 and 2)

SINE WAVE INPUT

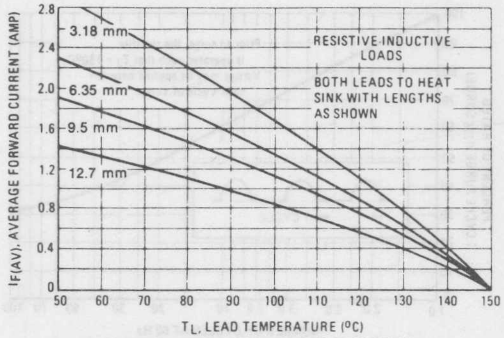


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

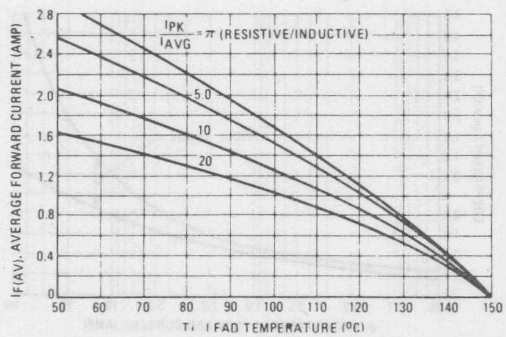


FIGURE 8 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

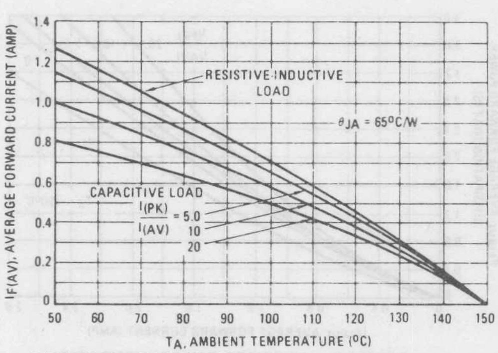


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

SQUARE WAVE INPUT

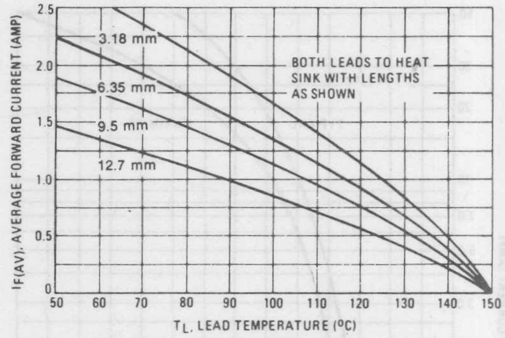


FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

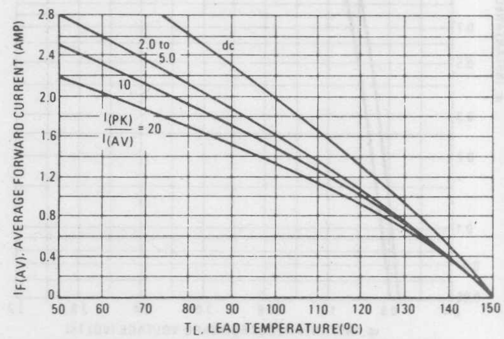


FIGURE 9 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

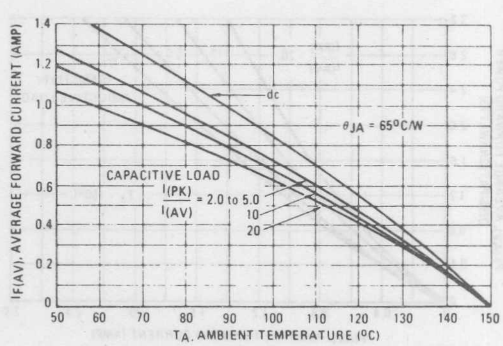


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

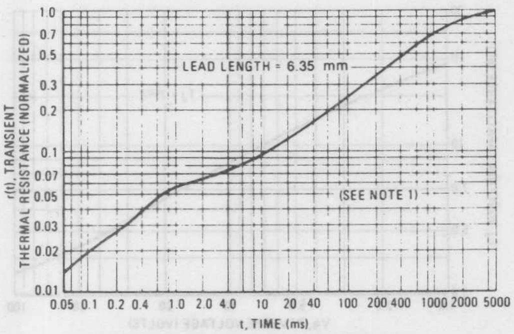


FIGURE 12 – THERMAL RESPONSE

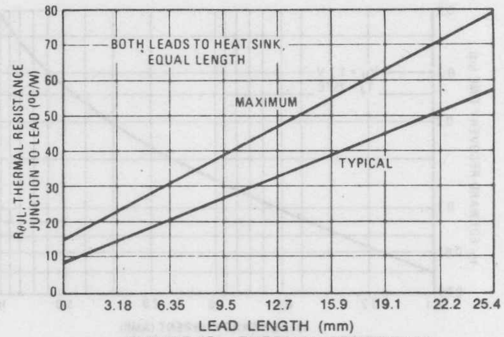
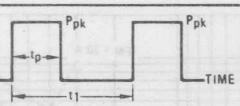


FIGURE 13 – THERMAL RESISTANCE

NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1) \right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 12, i.e.:

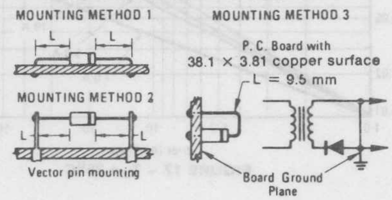
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

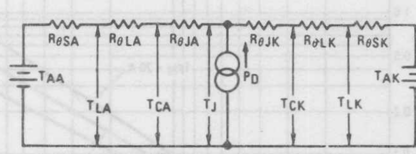
NOTE 2

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L(mm) 3.81	6.35	12.7	19.1	$R_{\theta JA}$
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W





Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.)

Values for thermal resistance components are:

$R_{\theta L}$ = 112°C/W/IN. Typically and 128°C/W/IN Maximum
$R_{\theta J}$ = 18°C/W Typically and 30°C/W Maximum

The maximum lead temperature may be calculated as follows:

$$T_L = 150° - \Delta T_{JL}$$

ΔT_{JL} can be calculated as shown in NOTE 1 or it may be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \bullet P_F$; P_F may be formulated for sine-wave operation from Figure 3 or from Figure 4 for square-wave operation.

FIGURE 14 – THERMAL CIRCUIT MODEL

TYPICAL DYNAMIC CHARACTERISTICS

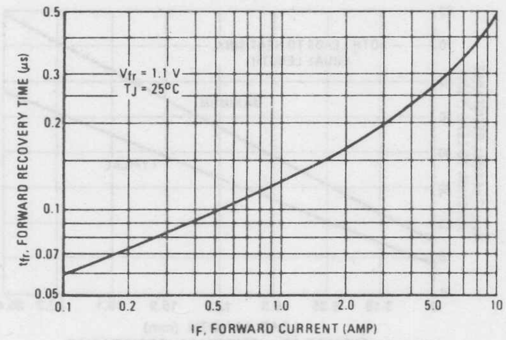


FIGURE 15 – FORWARD RECOVERY TIME

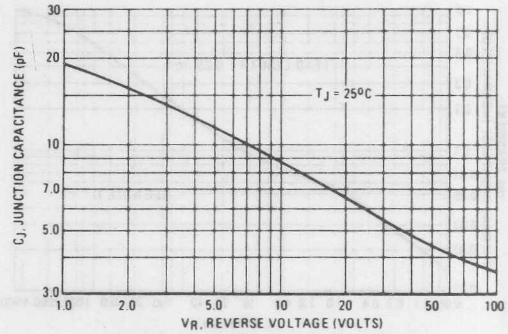


FIGURE 16 – JUNCTION CAPACITANCE

TYPICAL RECOVERED STORED CHARGE DATA
(SEE NOTE 3)

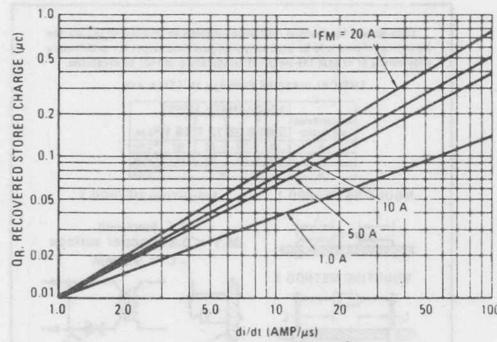


FIGURE 17 – T_J = 25°C

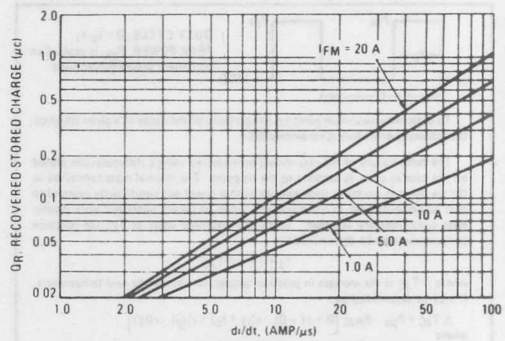


FIGURE 18 – T_J = 75°C

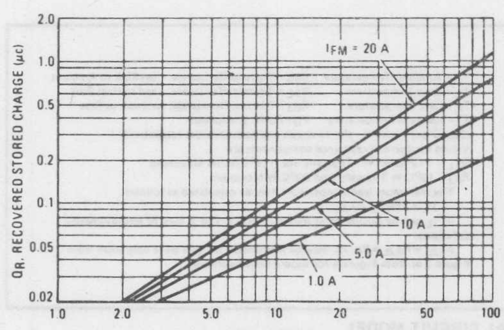


FIGURE 19 – T_J = 100°C

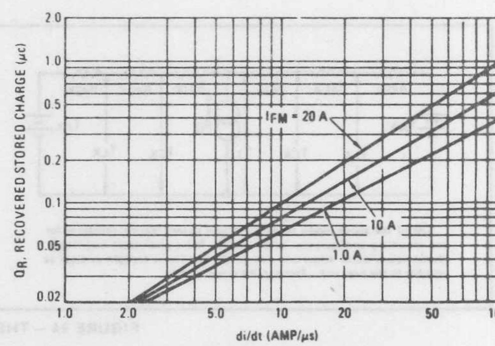


FIGURE 20 – T_J = 150°C

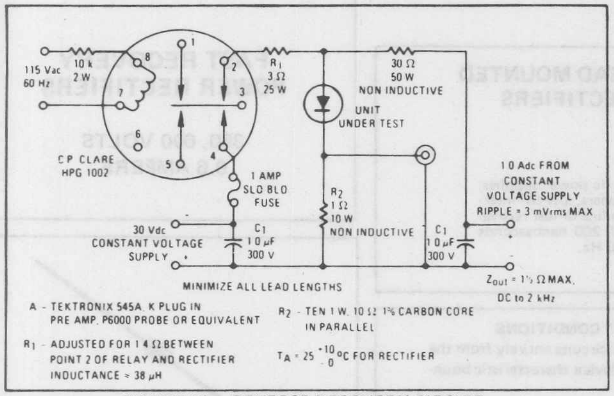


FIGURE 21 – REVERSE RECOVERY CIRCUIT

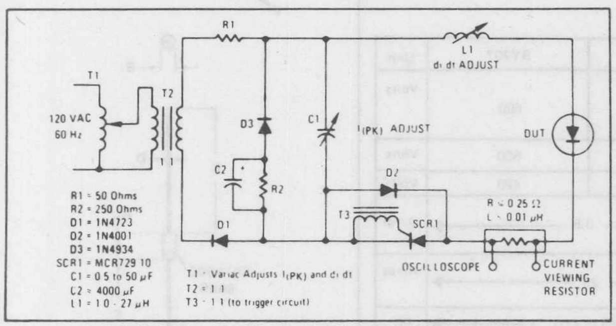


FIGURE 22 – JEDEC REVERSE RECOVERY CIRCUIT

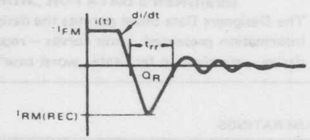
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

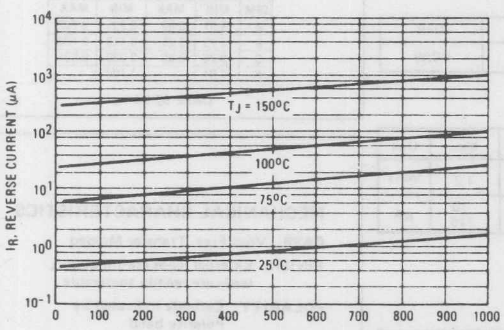


FIGURE 23 – TYPICAL REVERSE LEAKAGE

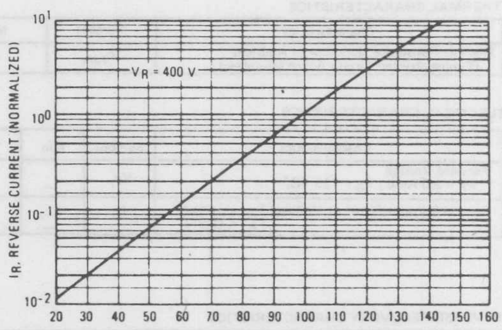


FIGURE 24 – TYPICAL REVERSE LEAKAGE

MOTOROLA

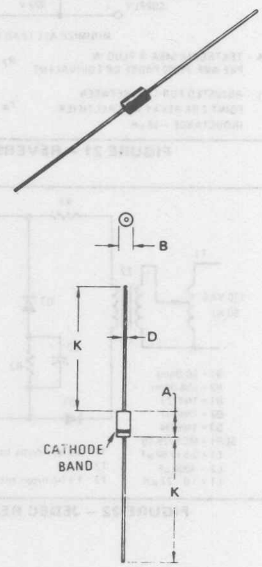
BY 206/207

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 200 nanoseconds providing high efficiency at frequencies to 250 Hz.

FAST RECOVERY POWER RECTIFIERS

350, 600 VOLTS
0.6 AMPERE



	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	-	1.100	-

CASE 59-04

DESIGNER'S DATA FOR „WORST CASE" CONDITIONS

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves – representing device characteristic boundaries – are given to facilitate „worst case" design.

MAXIMUM RATINGS

Ratings	Symbol	BY206	BY207	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RWM} V_{RRM} V_R	350	600	Volts
Non Repetitive Peak Reverse Voltage	V_{RSM}	450	800	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	250	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_A = 75^o$ C)	I_O	← 0.6 →		Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions) ($T_A = 25^o$ C)	I_{FSM}	← 25 →		Amps
Operating Junction Temp. Range	T_J	← –65 to +150 →		^{o}C
Storage Temperature Range	T_{stg}	← –65 to +175 →		^{o}C

THERMAL CHARACTERISTICS

Characteristics	Symbol	Max.	Unit
Thermal Resistance, Junction to Ambient (Typical Printed Circuit Board Mounting)	$R_{\theta JA}$	65	^{o}C/W

ELECTICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Forward Voltage (I_F = 2,0 Amp., T_A = 125 ^{o}C)	V_F	—	1.1	1.2	Volts
Reverse Current (Rated dc Voltage) $T_A = 25^o$ C $T_A = 100^o$ C	I_R	— —	1,0 5 0	10 125	μA

REVERSE RECOVERY CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time I_F = 10 mA to V_R = 50 V	t_{rr}	—	—	300	ns

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded

FINISH: External leads are tin plated, leads are readily solderable

POLARITY: Cathode indicated by Polarity band

WEIGHT: 0.4 Grams (Approximately)

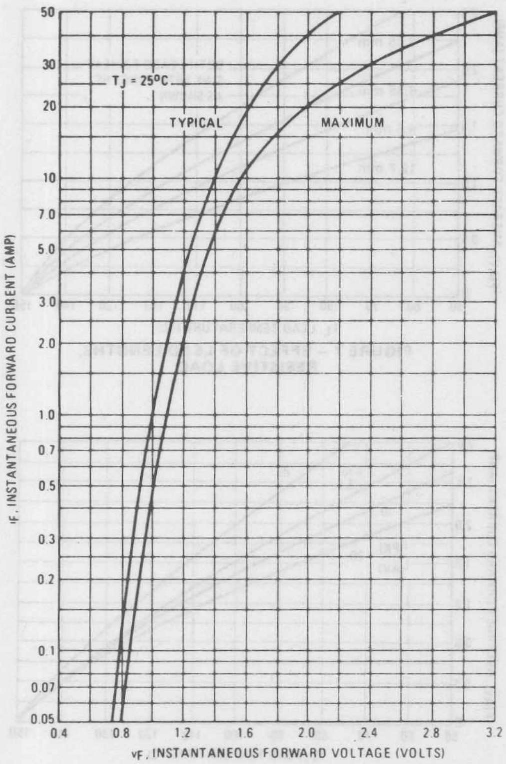


FIGURE 1 – FORWARD VOLTAGE

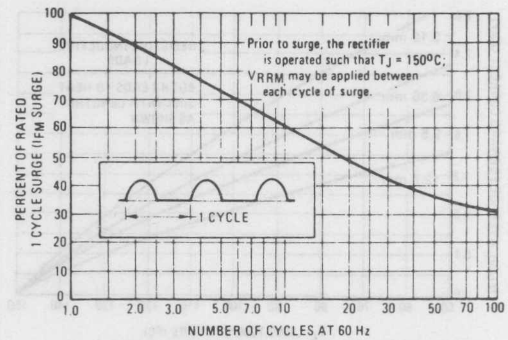


FIGURE 2 – MAXIMUM SURGE CAPABILITY

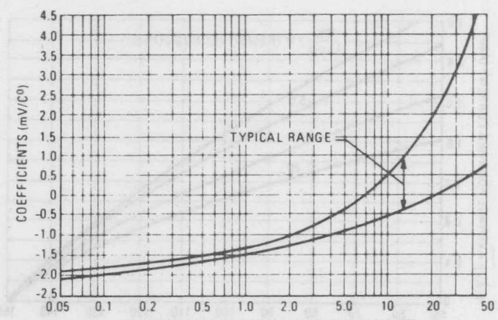


FIGURE 3 – TEMPERATURE COEFFICIENT

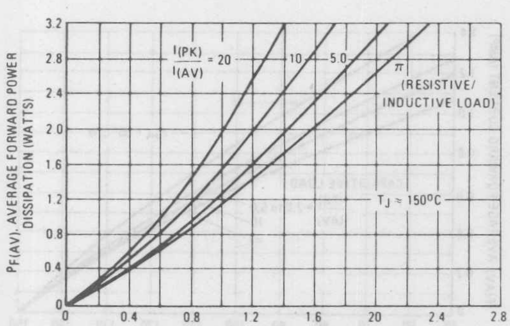


FIGURE 4 – FORWARD POWER DISSIPATION

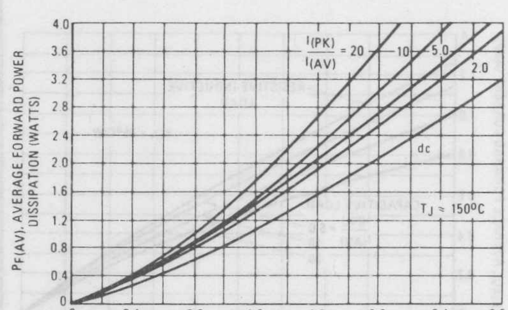


FIGURE 5 – FORWARD POWER DISSIPATION

MAXIMUM CURRENT RATINGS
(SEE NOTES 1 and 2)

SINE WAVE INPUT

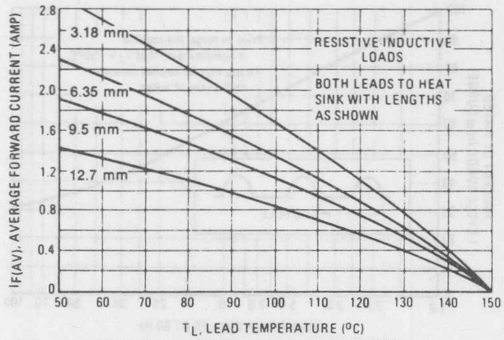


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

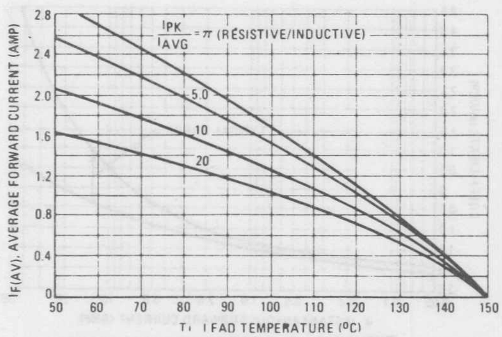


FIGURE 8 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

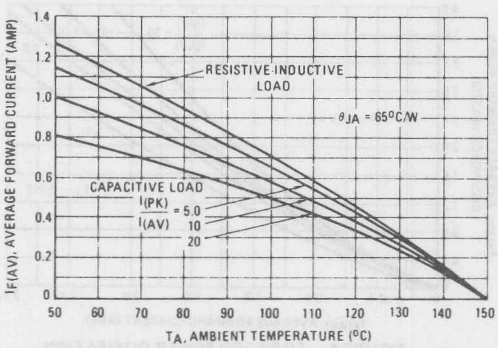


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

SQUARE WAVE INPUT

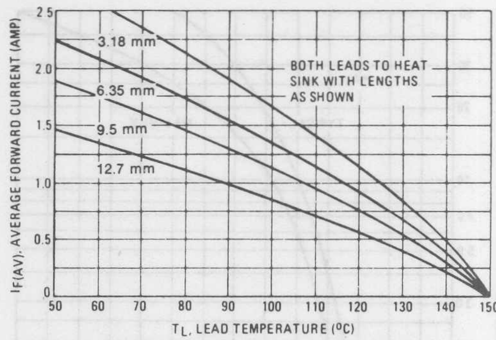


FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

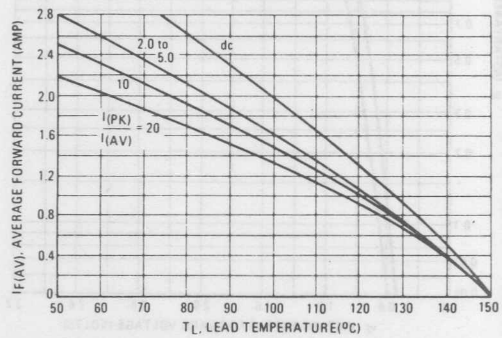


FIGURE 9 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

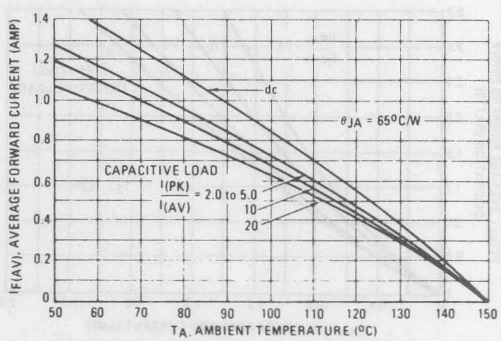


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

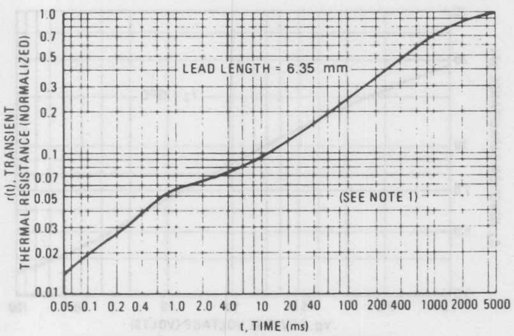


FIGURE 12 – THERMAL RESPONSE

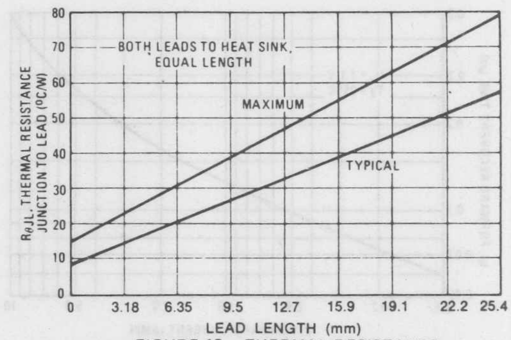
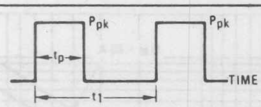


FIGURE 13 – THERMAL RESISTANCE

NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC}\left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)\right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 12, i.e.:

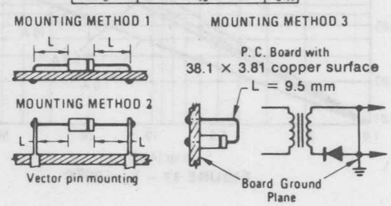
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

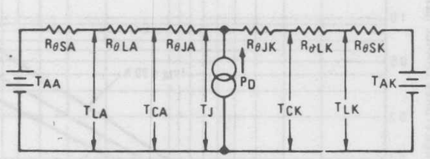
NOTE 2

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L(mm)				$R_{\theta JA}$
	3.81	6.35	12.7	19.1	
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W





Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature $R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
T_L = Lead Temperature $R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
T_C = Case Temperature $R_{\theta J}$ = Thermal Resistance, Junction to Case
T_J = Junction Temperature P_D = Power Dissipation
(Subscripts A and K refer to anode and cathode sides respectively.)
Values for thermal resistance components are:
$R_{\theta L}$ = 112°C/W/IN. Typically and 128°C/W/IN Maximum
$R_{\theta J}$ = 18°C/W Typically and 30°C/W Maximum

The maximum lead temperature may be calculated as follows:

$$T_L = 150^{\circ} - \Delta T_{JL}$$

ΔT_{JL} can be calculated as shown in NOTE 1 or it may be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \bullet P_F$; P_F may be formulated for sine-wave operation from Figure 3 or from Figure 4 for square-wave operation.

FIGURE 14 – THERMAL CIRCUIT MODEL

TYPICAL DYNAMIC CHARACTERISTICS

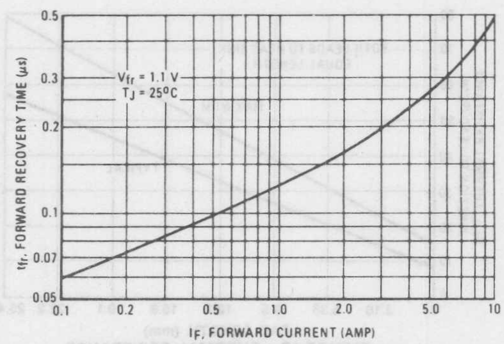


FIGURE 15 – FORWARD RECOVERY TIME

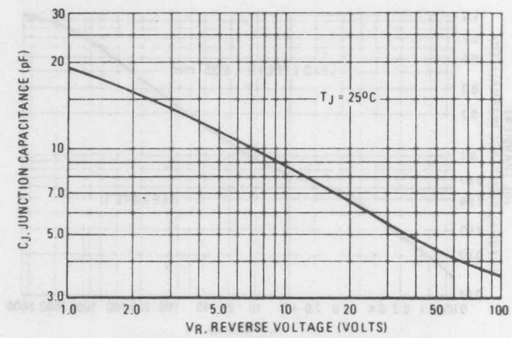


FIGURE 16 – JUNCTION CAPACITANCE

TYPICAL RECOVERED STORED CHARGE DATA
(SEE NOTE 3)

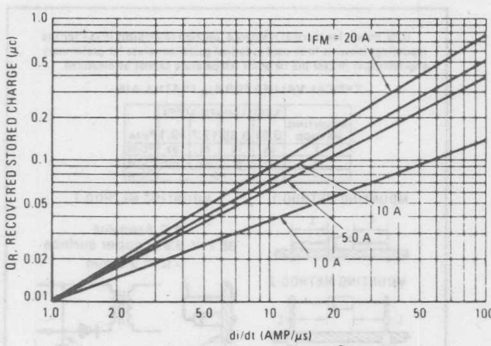


FIGURE 17 – T_J = 25°C

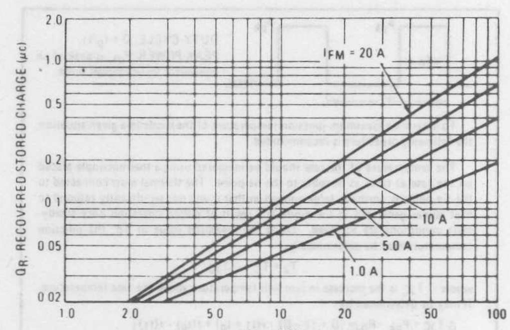


FIGURE 18 – T_J = 75°C

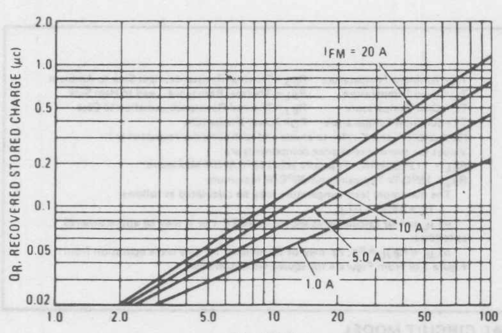


FIGURE 19 – T_J = 100°C

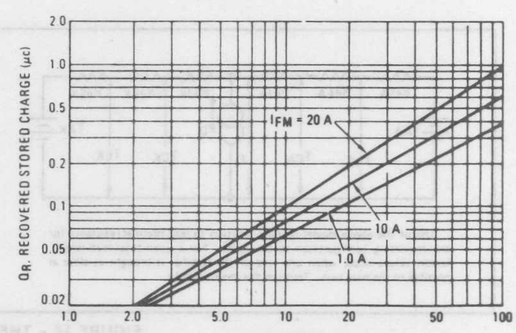


FIGURE 20 – T_J = 150°C

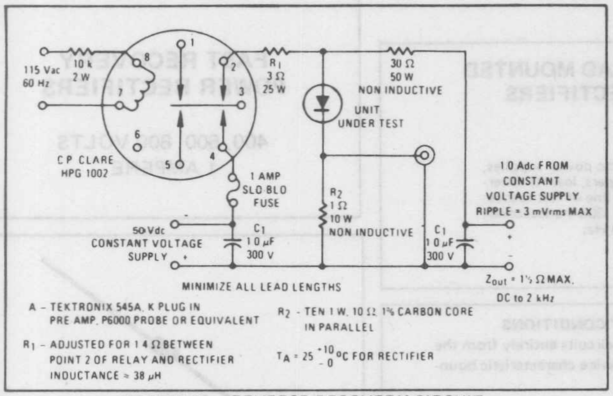


FIGURE 21 – REVERSE RECOVERY CIRCUIT

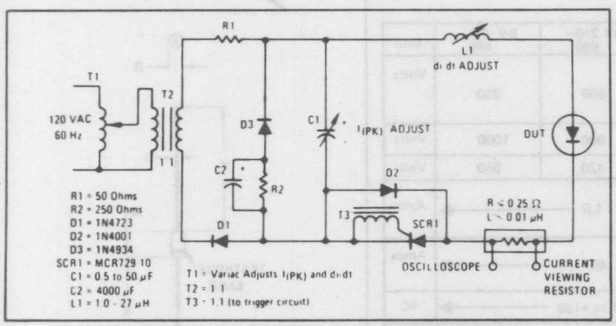


FIGURE 22 – JEDEC REVERSE RECOVERY CIRCUIT

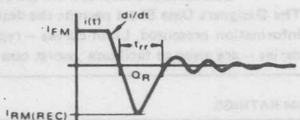
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 50 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

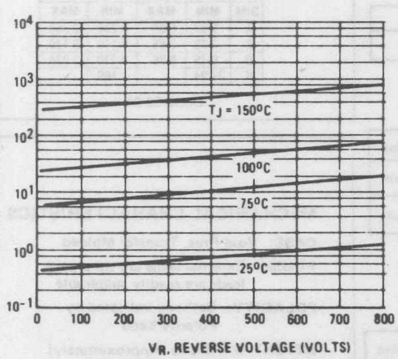


FIGURE 23 – TYPICAL REVERSE LEAKAGE

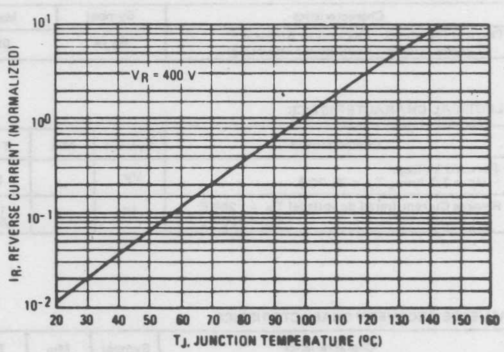


FIGURE 24 – TYPICAL REVERSE LEAKAGE

MOTOROLA

BY 210—400 SERIES

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

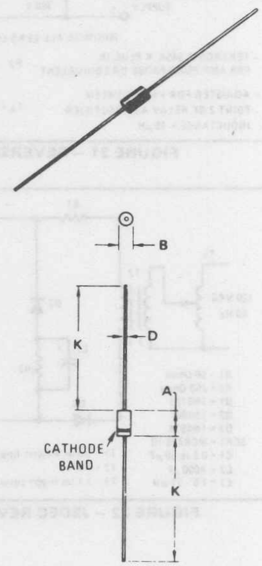
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 300 nanoseconds providing high efficiency at frequencies to 250 Hz.

FAST RECOVERY POWER RECTIFIERS

400, 600, 800 VOLTS
1 AMPERE

DESIGNER'S DATA FOR „WORST CASE" CONDITIONS

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves – representing device characteristic boundaries – are given to facilitate „worst case" design.



	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

CASE 59-04

MAXIMUM RATINGS

Ratings	Symbol	BY 210–400	BY 210–600	BY 210–800	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RWM} V_{RRM} V_R	400	600	800	Volts
Non Repetitive Peak Reverse Voltage	V_{RSM}	500	800	1000	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	280	420	560	Volts
Average Rectified Forward Current (Single phase, resistive load, T_A = 75° C)	I_O	← 1,0 →			Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions) (T_A = 75° C)	I_{FSM}	← 40 →			Amps
Operating Junction Temp. Range	T_J	← –65 to +150 →			°C
Storage Temperature Range	T_{stg}	← –65 to +175 →			°C

THERMAL CHARACTERISTICS

Characteristics	Symbol	Max.	Unit
Thermal Resistance, Junction to Ambient (Typical Printed Circuit Board Mounting)	$R_{\theta JA}$	65	°C/W

ELECTICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Forward Voltage (I_F = 2,0 Amp., T_A = 25 °C)	V_F	—	1,1	1,2	Volts
Reverse Current (rated dc voltage) T_A = 25° C T_A = 100° C	I_R	— —	1,0 5,0	10 100	μA

REVERSE RECOVERY CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time I_F = 10 mA to V_R = 50 V	t_{rr}	—	—	300	ns

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded

FINISH: External leads are tin plated, leads are readily solderable

POLARITY: Cathode indicated by Polarity band

WEIGHT: 0.4 Grams (Approximately)

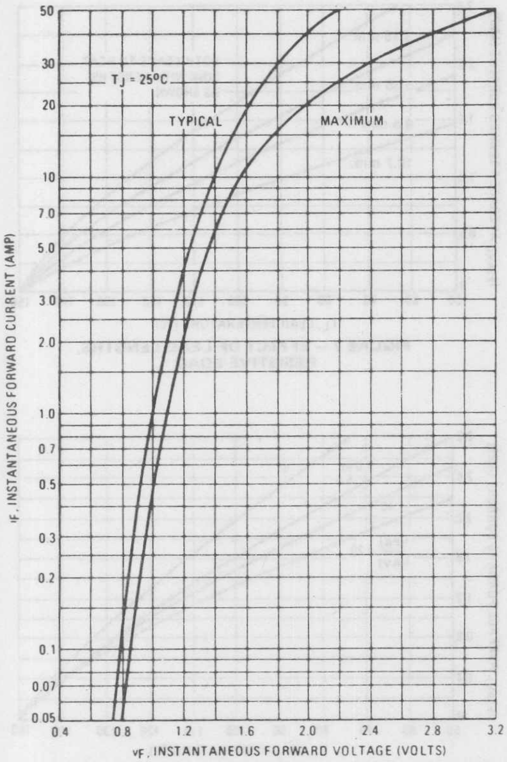


FIGURE 1 – FORWARD VOLTAGE

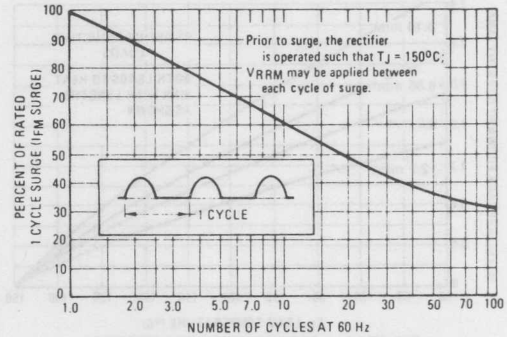


FIGURE 2 – MAXIMUM SURGE CAPABILITY

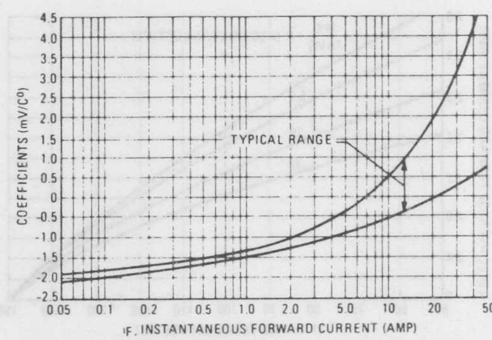


FIGURE 3 – TEMPERATURE COEFFICIENT

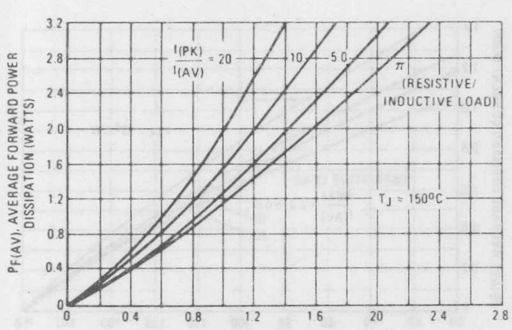


FIGURE 4 – FORWARD POWER DISSIPATION

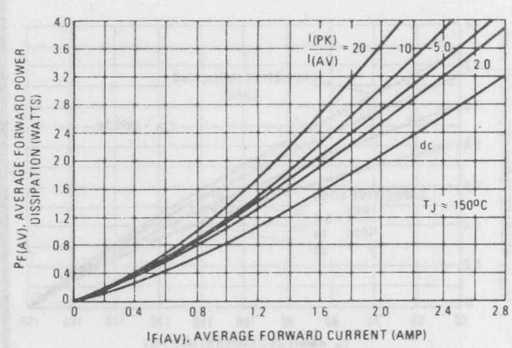


FIGURE 5 – FORWARD POWER DISSIPATION

MAXIMUM CURRENT RATINGS
(SEE NOTES 1 and 2)

SINE WAVE INPUT

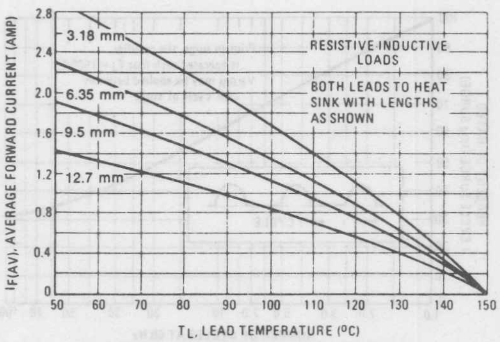


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

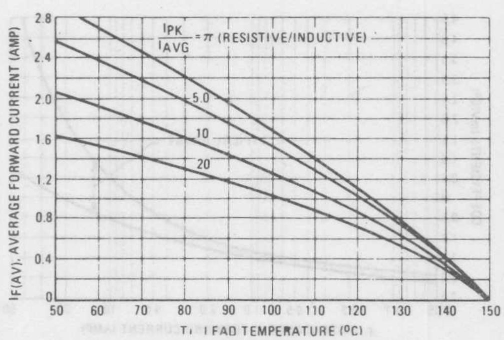


FIGURE 8 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

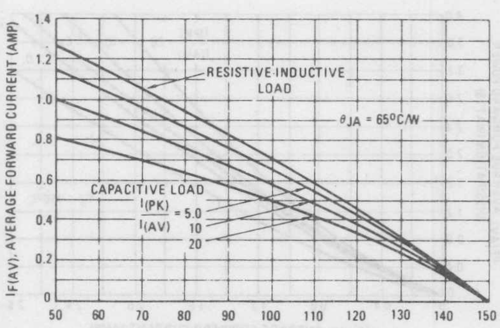


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

SQUARE WAVE INPUT

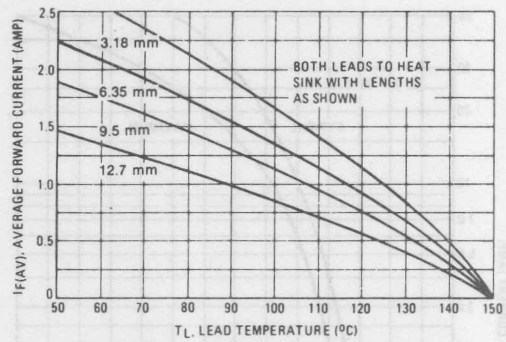


FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

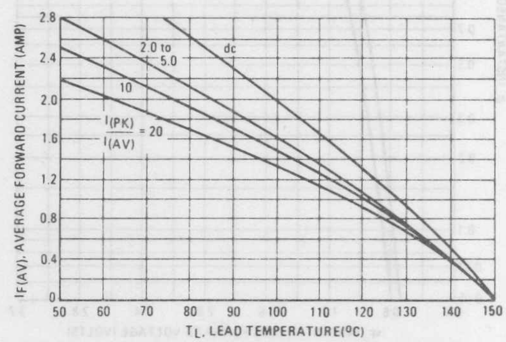


FIGURE 9 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

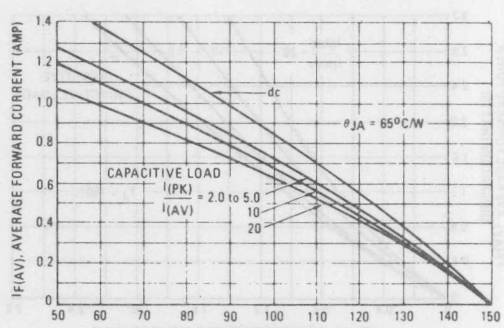


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

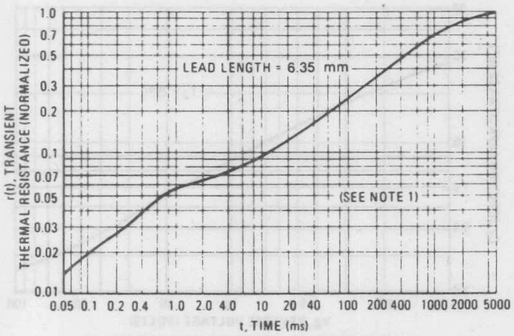


FIGURE 12 – THERMAL RESPONSE

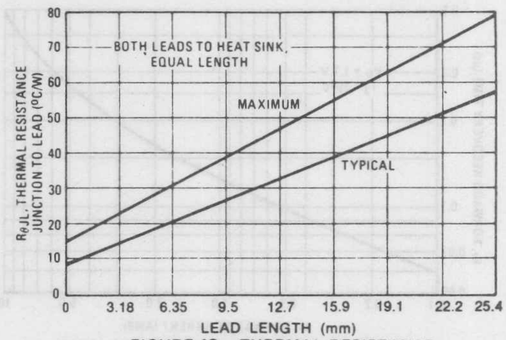
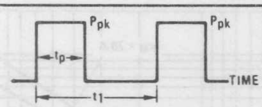


FIGURE 13 – THERMAL RESISTANCE

NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1) \right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 12, i.e.:

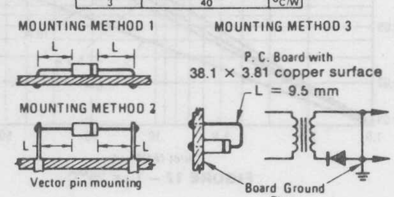
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

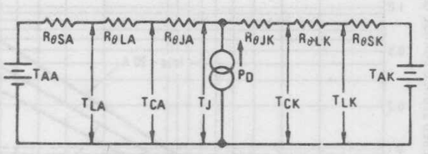
NOTE 2

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L(mm) 3.81	6.35	12.7	19.1	$R_{\theta JA}$
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W





Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature $R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
T_L = Lead Temperature $R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
T_C = Case Temperature $R_{\theta J}$ = Thermal Resistance, Junction to Case
T_J = Junction Temperature P_D = Power Dissipation
(Subscripts A and K refer to anode and cathode sides respectively.)

Values for thermal resistance components are:
$R_{\theta L}$ = 112°C/W/IN. Typically and 128°C/W/IN Maximum
$R_{\theta J}$ = 18°C/W Typically and 30°C/W Maximum

The maximum lead temperature may be calculated as follows:

$$T_L = 150° - \Delta T_{JL}$$

ΔT_{JL} can be calculated as shown in NOTE 1 or it may be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \bullet P_F$; P_F may be formulated for sine-wave operation from Figure 3 or from Figure 4 for square-wave operation.

FIGURE 14 – THERMAL CIRCUIT MODEL

TYPICAL DYNAMIC CHARACTERISTICS

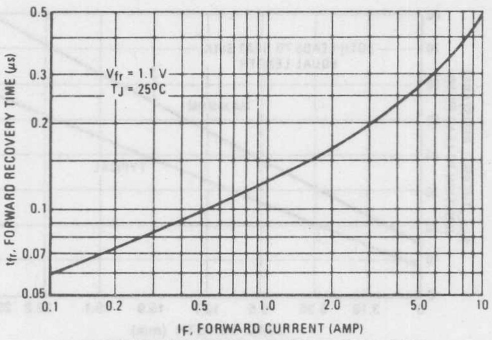


FIGURE 15 – FORWARD RECOVERY TIME

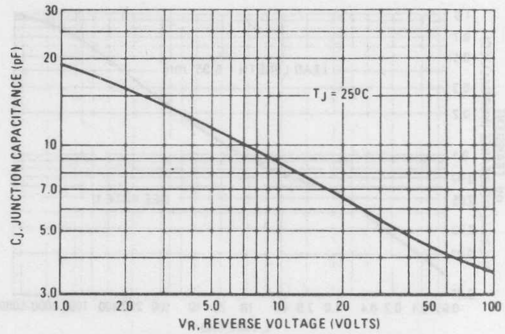


FIGURE 16 – JUNCTION CAPACITANCE

TYPICAL RECOVERED STORED CHARGE DATA
(SEE NOTE 3)

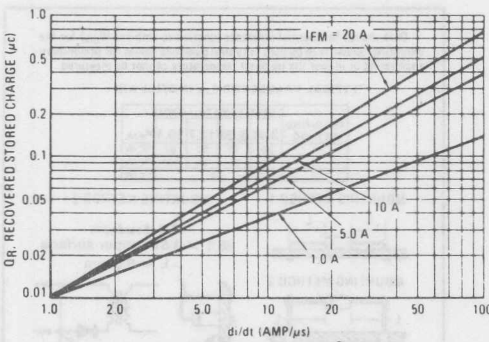


FIGURE 17 – T_J = 25°C

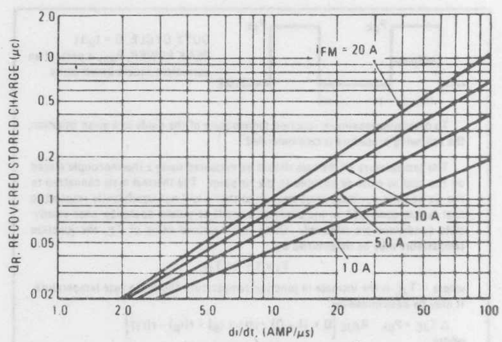


FIGURE 18 – T_J = 75°C

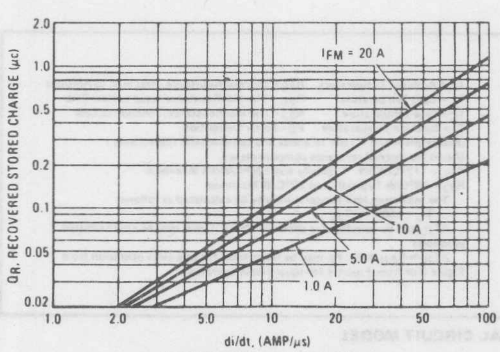


FIGURE 19 – T_J = 100°C

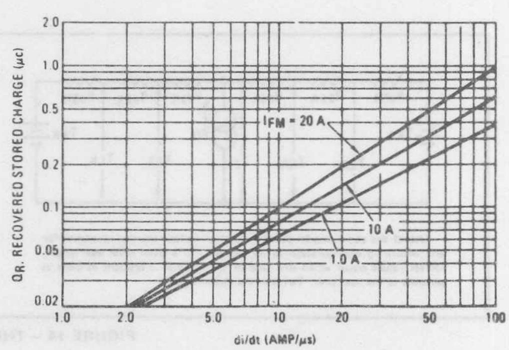


FIGURE 20 – T_J = 150°C

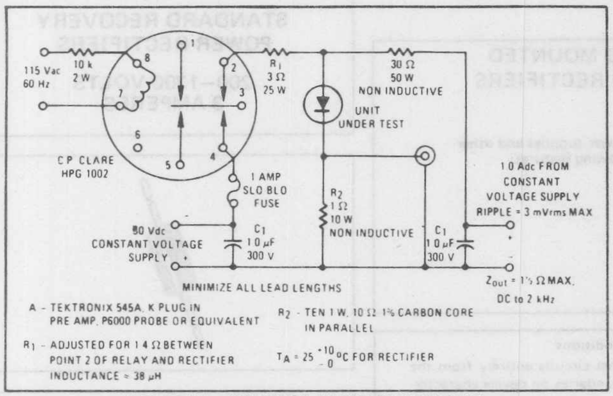


FIGURE 21 – REVERSE RECOVERY CIRCUIT

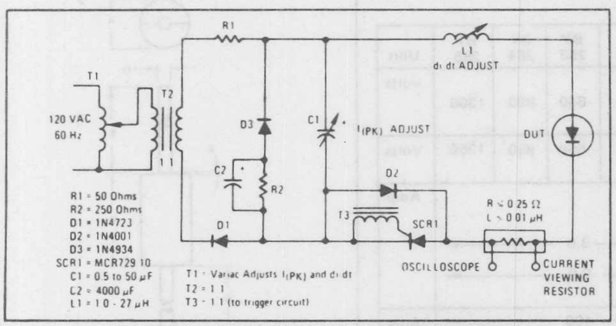


FIGURE 22 – JEDEC REVERSE RECOVERY CIRCUIT

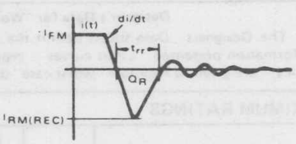
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 50 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

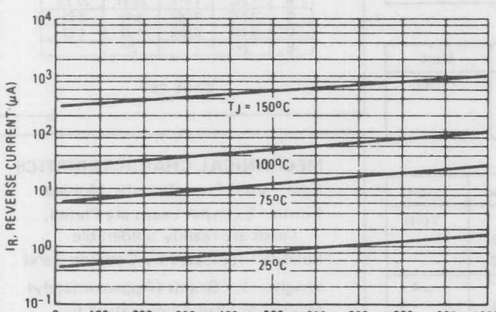


FIGURE 23 – TYPICAL REVERSE LEAKAGE

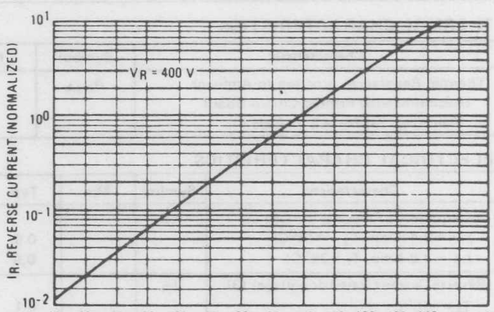


FIGURE 24 – TYPICAL REVERSE LEAKAGE

![MOTOROLA]

MOTOROLA

BY 251 SERIES

STANDARD RECOVERY POWER RECTIFIERS

200–1300 VOLTS
3 AMPERES

MINIATURE SIZE, AXIAL LEAD MOUNTED STANDARD RECOVERY POWER RECTIFIERS

. . . designed for use in T. V. line deflection, power supplies and other applications having need of a device with the following features:

— High Current to Small Size
— High Surge Current Capability
— Low Forward Voltage Drop
— Void-Free Economical Plastic Package
— Available in Volume Quantities

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

MAXIMUM RATINGS

Rating	Symbol	BY 251	BY 252	BY 253	BY 254	BY 255	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	200	400	600	800	1300	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	250	450	650	850	1350	Volts
Average Rectified Forward Current (Single phase resistive load, T_A = 95°C, PC Board Mounting) (1) (EIA Standard Conditions L = 1/32", T_L = 85°C)	I_O			3.0 8.0			Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}			100 (one cycle)			Amp
Operating and Storage Junction Temperature Range (2)	T_J, T_{stg}			-65 to +175			°C

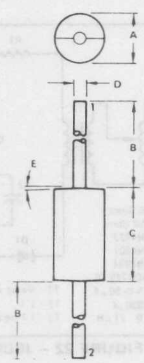
THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Recommended Printed Circuit Board Mounting, See Note 2 on Page 4).	$R_{\theta JA}$	28	°C/W

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (3) (i_F = 9.4 Amp, T_J = 175°C) (i_F = 3.0 Amp, T_J = 25°C)	v_F	 - -	 0.9 0.9	 1.0 1.0	Volts
Reverse Current (rated dc voltage) (3) T_J = 25°C T_J = 100°C	I_R		 0.1 2.8	 10 500	μA

(1) Derate for reverse power dissipation. See Note on Page 2.
(2) Derate as shown in Figure 1.
(3) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%



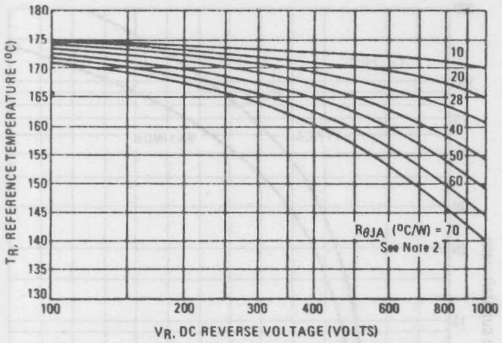
	INCHES		MILLIMETERS	
A	0.190	0.210	4.83	5.33
B	1.062	1.072	26.97	27.23
C	0.370	0.380	9.40	9.65
D	0.048	0.052	1.22	1.32
E	2°		2°	

CASE 267

MECHANICAL CHARACTERISTICS

Case: Void Free, Transfer Molded
Finish: External Leads are Plated, Leads are readily Solderable
Polarity: Indicated by Cathode Band
Weight: 1.1 Grams (Approximately)
Maximum Lead Temperature for Soldering Purposes:
300°C, 1/8" from case for 10 s at 5.0 lb. tension

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE



CURRENT DERATING
(Reverse Power Loss Neglected)

FIGURE 3 – PC BOARD MOUNTING

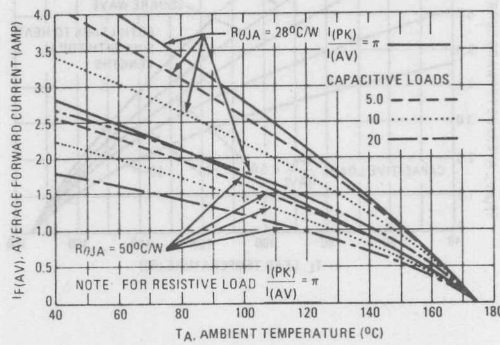


FIGURE 2 – MAXIMUM SURGE CAPABILITY

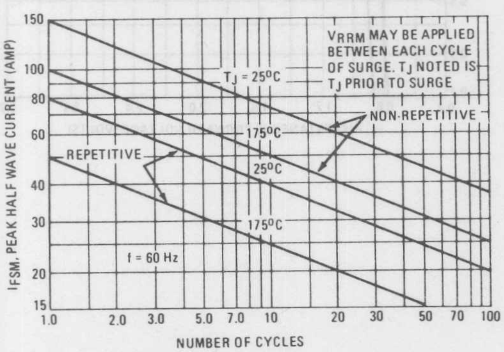


FIGURE 4 – SEVERAL LEAD LENGTHS

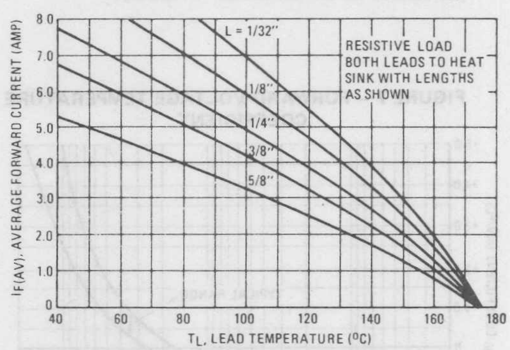


FIGURE 5 – 1/8" LEAD LENGTH

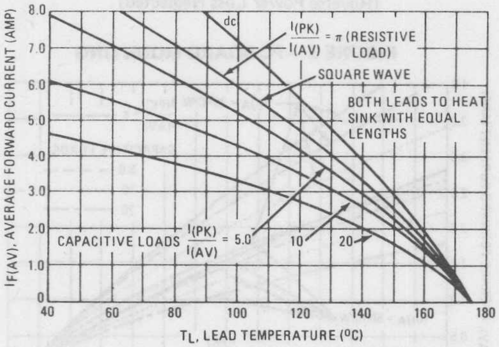


FIGURE 6 – MAXIMUM FORWARD VOLTAGE

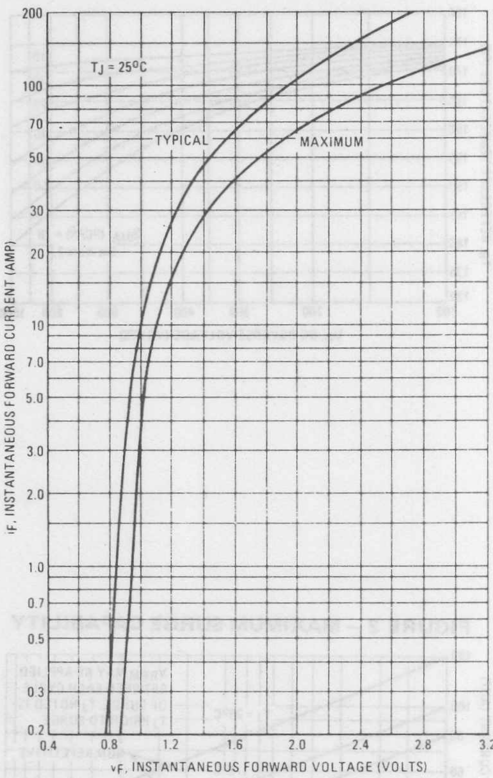


FIGURE 7 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

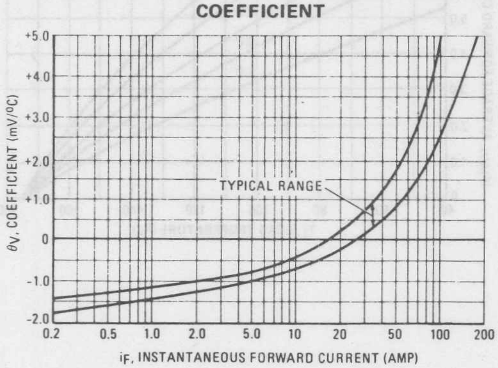


FIGURE 8 – FORWARD POWER DISSIPATION

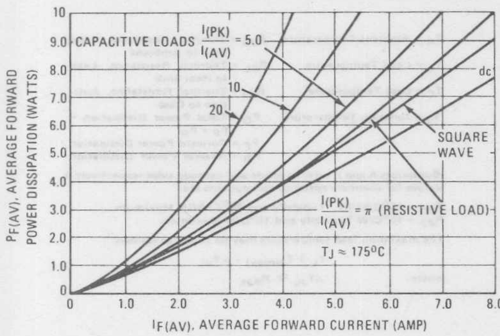
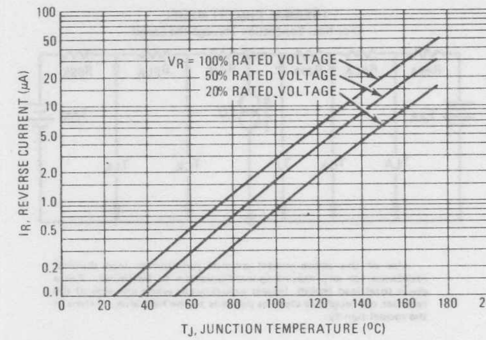


FIGURE 9 – TYPICAL REVERSE CURRENT



THERMAL CHARACTERISTICS

FIGURE 10 – THERMAL RESPONSE

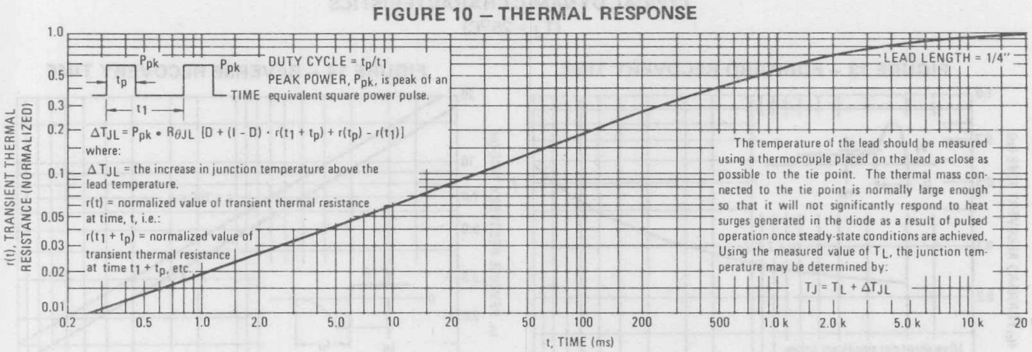
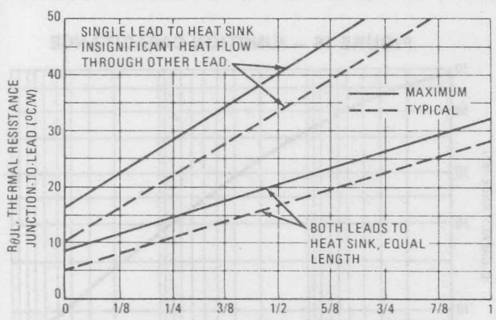


FIGURE 11 – STEADY-STATE THERMAL RESISTANCE



NOTE 1 – AMBIENT MOUNTING DATA

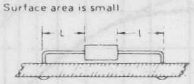
Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN)				$R_{\theta JA}$
	1/8	1/4	1/2	3/4	
1	50	51	53	55	$^oC/W$
2	58	59	61	63	$^oC/W$
3		28			$^oC/W$

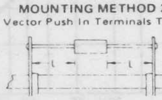
MOUNTING METHOD 1

P.C. Board Where Available Copper Surface area is small.



MOUNTING METHOD 2

Vector Push In Terminals T-28



MOUNTING METHOD 3

P.C. Board with 1-1/2" x 1-1/2" Copper Surface

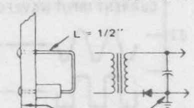
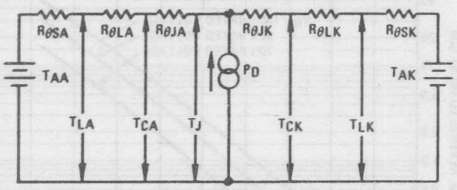


FIGURE 12 – APPROXIMATE THERMAL CIRCUIT MODEL

THERMAL CIRCUIT MODEL
(For Heat Conduction Through the Leads)



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Total Power Dissipation = $P_F + P_R$
P_F = Forward Power Dissipation
P_R = Reverse Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.) Values for thermal resistance components are:

$R_{\theta L}$ = 46°C/W/IN. Typically and 48°C/W/IN Maximum.
$R_{\theta J}$ = 10°C/W Typically and 16°C/W Maximum.

The maximum lead temperature may be found as follows:

$$T_L = T_{J(max)} - \Delta T_{JL}$$

where $\Delta T_{JL} \approx R_{\theta JL}$

TYPICAL DYNAMIC CHARACTERISTICS

($T_J = 25°C$)

FIGURE 13 – FORWARD RECOVERY TIME

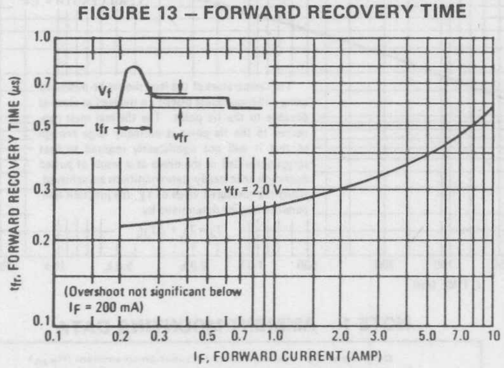


FIGURE 14 – REVERSE RECOVERY TIME

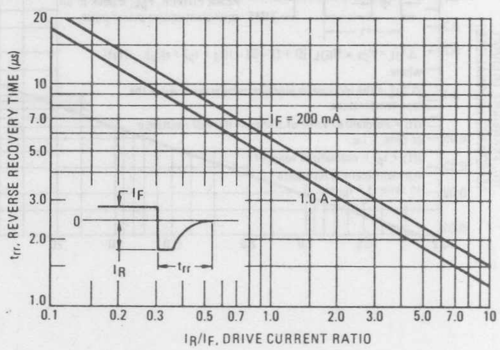


FIGURE 15 – RECTIFICATION WAVEFORM EFFICIENCY

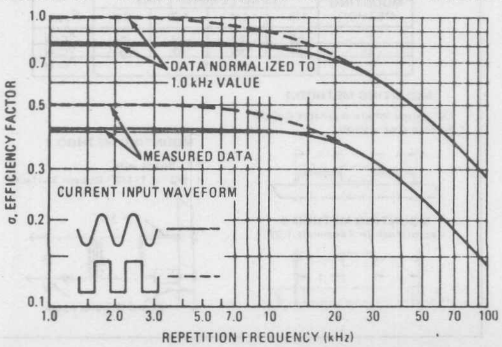
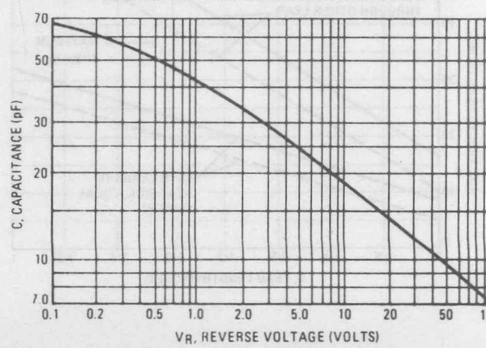


FIGURE 16 – JUNCTION CAPACITANCE



MOTOROLA

BY 296 SERIES

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED SOFT RECOVERY POWER RECTIFIERS

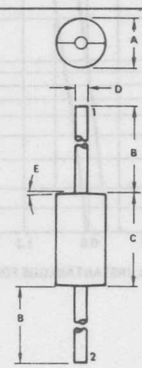
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 300 nanoseconds providing high efficiency at frequencies to 250 Hz.

DESIGNER'S DATA FOR „WORST CASE" CONDITIONS

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves – representing device characteristic bounderies – are given to facilitate „worst case" design.

SOFT RECOVERY POWER RECTIFIERS

100–800 VOLTS
2,0 AMPERES



	INCHES		MILLIMETERS	
A	0.190	0.210	4.83	5.33
B	1.062	1.072	26.97	27.23
C	0.370	0.380	9.40	9.65
D	0.048	0.052	1.22	1.32
E	2°		2°	

CASE 267

MAXIMUM RATINGS

Ratings	Symbol	BY296	BY297	BY298	BY299	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RWM} V_{RRM} V_R	100	200	400	800	Volts
Non Repetitive Peak Reverse Voltage	V_{RSM}	200	300	500	1000	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	70	140	280	560	Volts
Average Rectified Forward Current (Single phase, resistive load, T_A = 90° C)	I_O	← 2 0 →				Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	← 70 (one cycle) →				Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← –65 to +175 →				°C

THERMAL CHARACTERISTICS

Characteristics	Symbol	Max.	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	28	°C

ELECTRICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Forward Voltage (I_F = 3,0 Amp., T_J = 25° C)	V_F	—		1,25	Volts
Reverse Current (rated dc voltage) T_J = 25° C	I_R	—		10	µA

REVERSE RECOVERY CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time I_F = 10 mA, to I_{RM} = 10 mA, 1 mA	t_{rr}	—	—	500	ns
I_F = 1 Amp. to V_R = 30 V_{DC}	t_{rr}			300	ns

MECHANICAL CHARACTERISTICS

CASE . . . . Void free, transfer molded
FINISH. . . . . .All external surfaces corrosion-resistant and the terminal leads are readily solderable
POLARITY . . . . Cathode indicated by polarity band
MOUNTING POSITIONS . . . . Any
SOLDERING . . . . . .220°C 1/16" from case for ten seconds

FIGURE 1 – FORWARD VOLTAGE

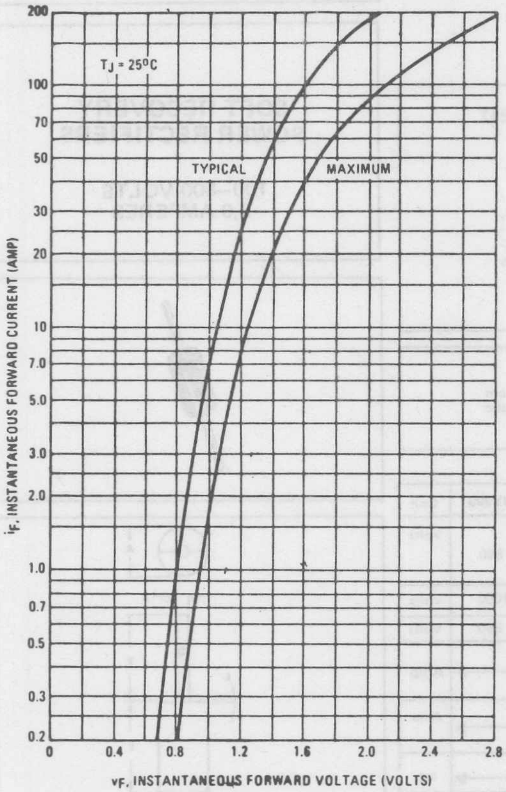


FIGURE 3 – REVERSE POWER DISSIPATION, SINE WAVE

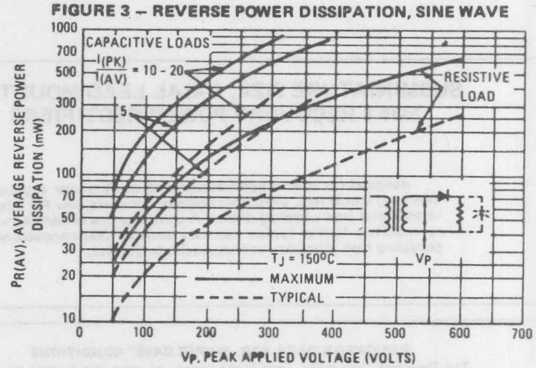


FIGURE 4 – REVERSE POWER DISSIPATION, SQUARE WAVE

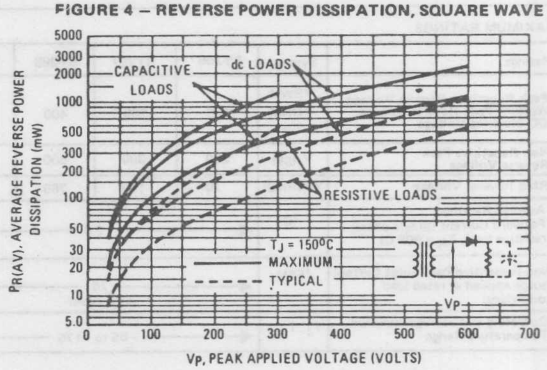
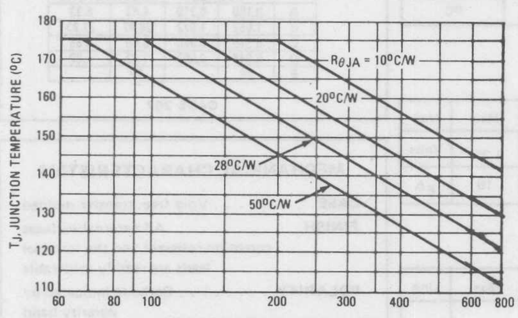


FIGURE 2 – MAXIMUM ALLOWABLE JUNCTION TEMPERATURE



NOTE 1
MAXIMUM JUNCTION TEMPERATURE DERATING

When operating this rectifier at junction temperatures over 120° C, reverse power dissipation and the possibility of thermal runaway must be considered. The data of Figure 2 is based upon worst case reverse power and should be used to derate $T_{J(max)}$ from its maximum value of 175° C.

FIGURE 5 – NORMALIZED REVERSE CURRENT

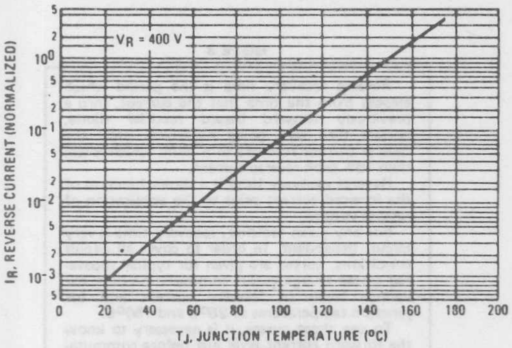
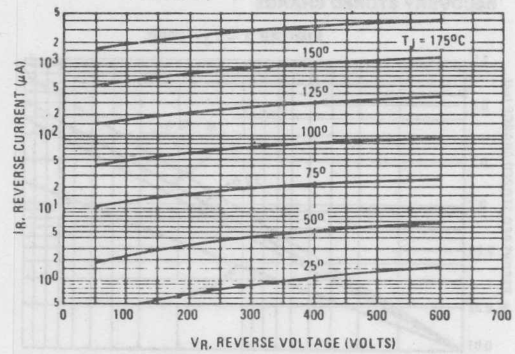


FIGURE 6 – TYPICAL REVERSE CURRENT



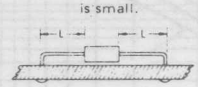
NOTE 2 – MOUNTING DATA

Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering, or in case the tie point temperature cannot be measured.

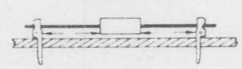
TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

Mounting Method	Lead Length, L (in) 1/8	1/4	1/2	3/4	$R_{\theta JA}$
1	50	51	53	55	°C/W
2	58	59	61	63	°C/W
3		28			°C/W

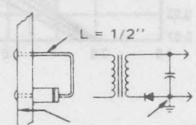
Mounting Method 1
P.C. Board where available copper surface is small.



Mounting Method 2
Vector Push-In Terminals T-28

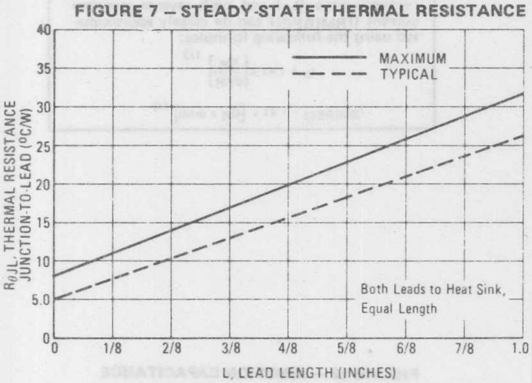


Mounting Method 3
P.C. Board with with 2-1/2" X 2-1/2" copper surface.



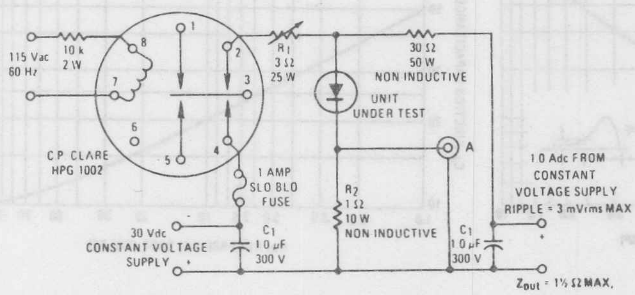
Board Ground Plane

FIGURE 7 – STEADY-STATE THERMAL RESISTANCE



DYNAMIC CHARACTERISTICS

FIGURE 8 – REVERSE RECOVERY CIRCUIT



MINIMIZE ALL LEAD LENGTHS

A – TEKTRONIX 545A, K PLUG IN PRE AMP, P6000 PROBE OR EQUIVALENT

R_1 – ADJUSTED FOR 1.4 Ω BETWEEN POINT 2 OF RELAY AND RECTIFIER INDUCTANCE ≈ 38 μH

R_2 – TEN 1 W, 10 Ω, 1% CARBON CORE IN PARALLEL

$T_A = 25^{+10}_{-0}$ °C FOR RECTIFIER

RECOVERY STORED CHARGE

FIGURE 9 – $T_J = 25^oC$

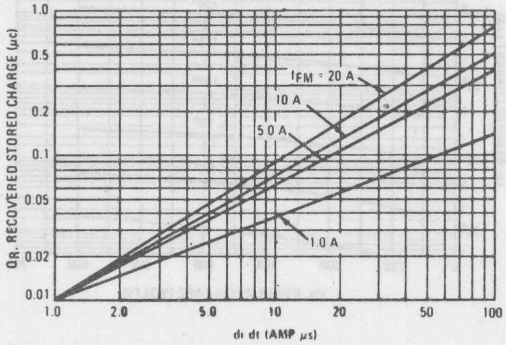
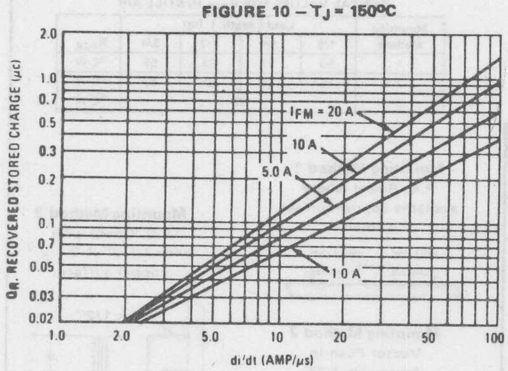


FIGURE 10 – $T_J = 150^oC$



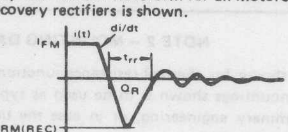
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passers thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C and 150°C.

To use these curses, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

FIGURE 11 – FORWARD RECOVERY TIME

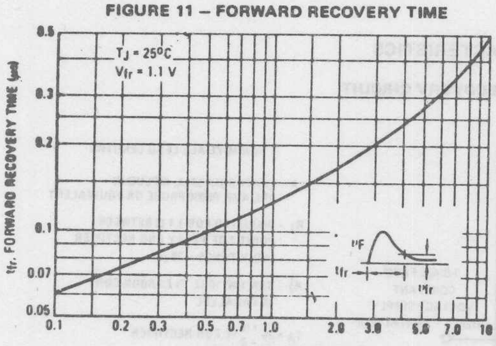
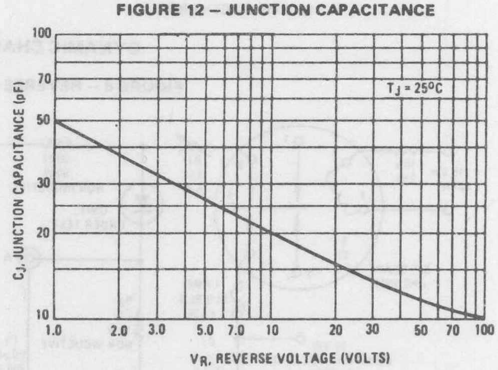


FIGURE 12 – JUNCTION CAPACITANCE

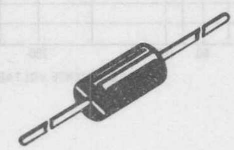


MOTOROLA

BY 396 SERIES

FAST RECOVERY POWER RECTIFIERS

100–800 VOLTS
3,0 AMPERES



SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 100 nanoseconds providing high efficiency at frequencies to 250 kHz.

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

MAXIMUM RATINGS

Rating	Symbol	BY396	BY397	BY398	BY399	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	100	200	400	800	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	200	300	500	1000	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	70	140	280	560	Volts
Average Rectified Forward Current (Single phase resistive load, $T_A = 90^oC$) (1)	I_O	← 3.0 →				Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	← 100 (one cycle) →				Amp
Operating and Storage Junction Temperature Range (2)	T_J, T_{stg}	← -65 to +175 →				^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Recommended Printed Circuit Board Mouting, See Note 6, Page 8)	$R_{\theta JA}$	28	$^oC/W$

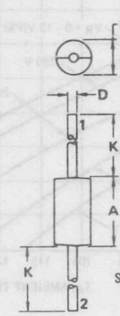
ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (I_F = 9.4 Amp, $T_J = 175^oC$)	v_F	–	0.9	1.1	Volts
Forward Voltage (I_F = 3.0 Amp, $T_J = 25^oC$)	V_F	–	1.04	1.25	Volts
Reverse Current (rated dc voltage) $T_J = 25^oC$	I_R	–	2.0	10	μA
$T_J = 100^oC$				300	

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 25) (I_F = 10 mA, I_{RR} = 10 mA, 1 mA)	t_{rr}	 – –	 100 150	 200 400	ns
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 25)	$I_{RM(REC)}$	–	–	2.0	Amp

(1) Must be derated for reverse power dissipation. See Note 2.
(2) Derate as shown in Figure 1



STYLE 1:
PIN 1. CATHODE
2. ANODE

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	9.65	0.370	0.380
B	4.83	5.33	0.190	0.210
D	1.22	1.32	0.048	0.052
K	26.97	27.23	1.062	1.072

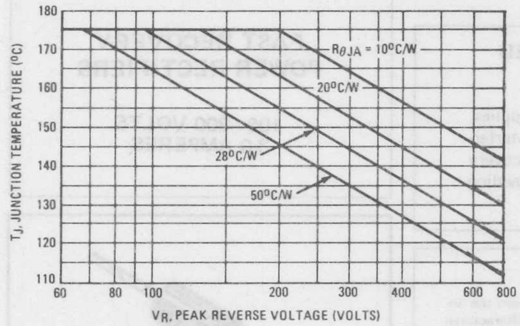
CASE 267-01

MECHANICAL CHARACTERISTICS

Case: Void Free, Transfer Molded
Finish: External Leads are Plated, Leads are readily Solderable
Polarity: Indicated by Cathode Band
Weight: 1.1 Grams (Approximately)
Maximum Lead Temperature for Soldering Purposes:
240°C, 1/8" from case for 10 s at 5.0 lb. tension

MAXIMUM CURRENT AND TEMPERATURE RATINGS

FIGURE 1 – MAXIMUM ALLOWABLE JUNCTION TEMPERATURE



NOTE 1
MAXIMUM JUNCTION TEMPERATURE DERATING

When operating this rectifier at junction temperatures over 120°C, reverse power dissipation and the possibility of thermal runaway must be considered. The data of Figure 1 is based upon worst case reverse power and should be used to derate $T_{J(max)}$ from its maximum value of 175°C. See Note 2 for additional information on derating for reverse power dissipation.

When current ratings are computed from $T_{J(max)}$ and reverse power dissipation is also included, ratings vary with reverse voltage as shown on Figures 2 thru 5.

RESISTIVE LOAD RATINGS

Printed Circuit Board Mounting – See Note 6, Page 8

FIGURE 2 – SINE WAVE INPUT

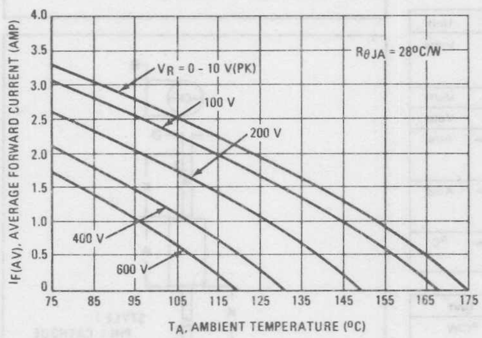


FIGURE 3 – SQUARE WAVE INPUT

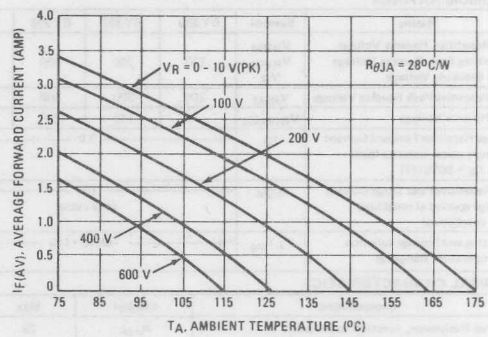


FIGURE 4 – SINE WAVE INPUT

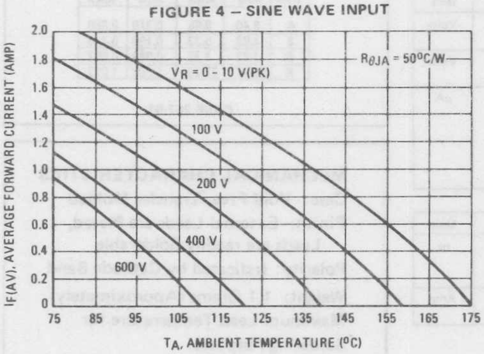
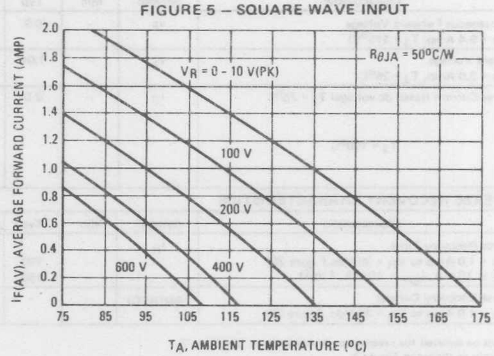


FIGURE 5 – SQUARE WAVE INPUT



MAXIMUM CURRENT RATINGS

Current derating data is based upon the thermal response data of Figure 29 and the forward power dissipation data of Figures 19 and 20. Since reverse power dissipation is not considered in Figures 6 thru 11, additional derating for reverse voltage and for junction to ambient thermal resistance must be applied. See Note 2.

SINE WAVE INPUTS

FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

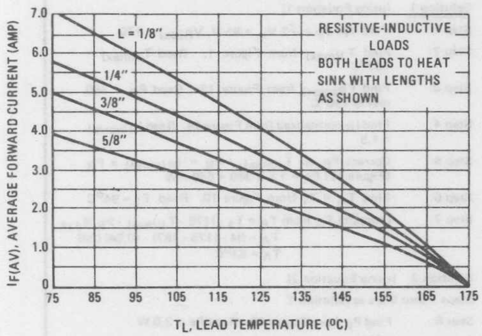


FIGURE 8 – 1/8" LEAD LENGTH, VARIOUS LOADS

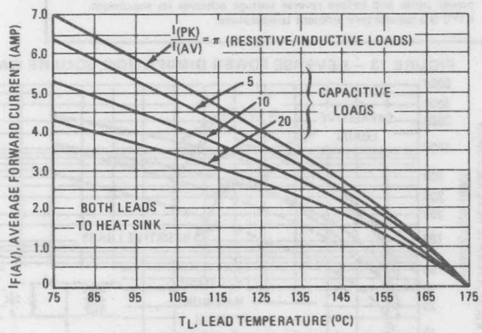
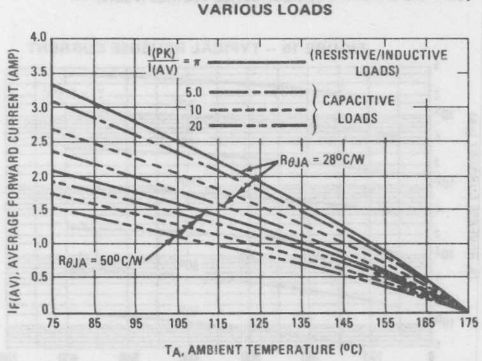


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS



SQUARE WAVE INPUTS

FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

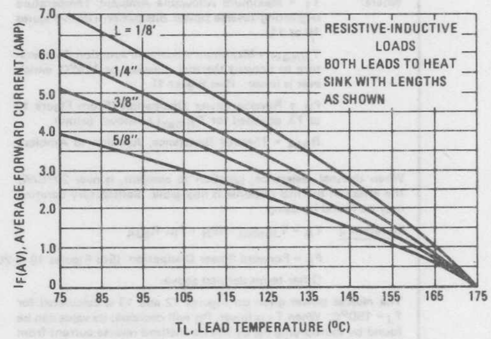


FIGURE 9 – 1/8" LEAD LENGTH, VARIOUS LOADS

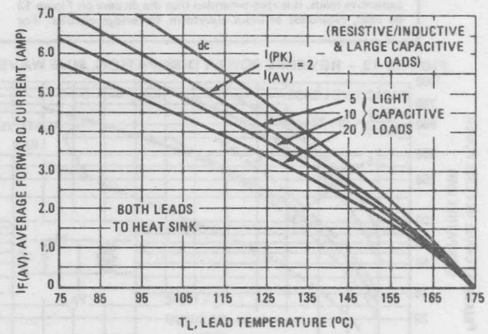
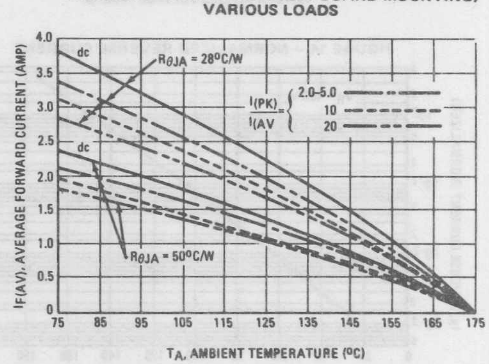


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS



REVERSE POWER DISSIPATION AND CURRENT

NOTE 2
DERATING FOR REVERSE POWER DISSIPATION

In this rectifier, power loss due to reverse current is generally not negligible. For reliable circuit design, the maximum junction temperature must be limited to either 175°C or the temperature which results in thermal runaway. Proper derating may be accomplished by use of equation 1 or equation 2.

Equation 1 $T_A = T_1 - (175 - T_{J(max)}) - P_R R_{\theta JA}$

Where: T_1 = Maximum Allowable Ambient Temperature neglecting reverse power dissipation (from Figures 10 or 11)

$T_{J(max)}$ = Maximum Allowable Junction Temperature to prevent thermal runaway or 175°C, which ever is lower. (See Figure 1).

P_R = Reverse Power Dissipation (From Figure 12 or 13, adjusted for $T_{J(max)}$ as shown below)

$R_{\theta JA}$ = Thermal Resistance, Junction to Ambient.

When thermal resistance, junction to ambient, is over 20°C/W, the effect of thermal response is negligible. Satisfactory derating may be found by using:

Equation 2 $T_A = T_{J(max)} - (P_R + P_F) R_{\theta JA}$

P_F = Forward Power Dissipation (See Figures 19 & 20)

Other terms defined above.

The reverse power given on Figures 12 and 13 is calculated for $T_J = 150°C$. When T_J is lower, P_R will decrease; its value can be found by multiplying P_R by the normalized reverse current from Figure 14 at the temperature of interest.

The reverse power data is calculated for half wave rectification circuits. For full wave rectification using either a bridge or a center-tapped transformer, the data for resistive loads is equivalent when V_P is the line to line voltage across the rectifiers. For capacitive loads, it is recommended that the dc case on Figure 13 be used, regardless of input waveform, for bridge circuits. For capacitively loaded full wave center-tapped circuits, the 20:1 data of Figure 12 should be used for sine wave inputs and the capacitive load data of Figure 13 should be used for square wave inputs regardless of $I_{(pk)}/I_{(av)}$. For these two cases, V_P is the voltage across one leg of the transformer.

Example 1 Find maximum ambient temperature for I_{AV} = 2 A, capacitive load of I_{PK}/I_{AV} = 20, Input Voltage = 60 V (rms), sine wave, $R_{\theta JA}$ = 28°C/W, half wave circuit.

Solution 1 (using Equation 1)

Step 1: Find V_P; $V_P = \sqrt{2}\, V_{in}$ = 85 V, $V_{R(pk)}$ = 170

Step 2: Find $T_{J(max)}$ from Figure 1. Read $T_{J(max)}$ = 157°C

Step 3: Find $P_{R(max)}$ from Figure 12. Read P_R = 360 mW @ 150°C

Step 4: Find I_R normalized from Figure 14. Read $I_{R(norm)}$ = 1.5

Step 5: Correct P_R to $T_{J(max)}$. $P_R = I_{R(norm)} \times P_R$ (Figure 12) P_R = 1.5 x 360 = 540 mW

Step 6: Find $T_A = T_1$ from Figure 10. Read T_1 = 94°C

Step 7: Compute T_A from $T_A = T_1 - (175 - T_{J(max)} - P_R R_{\theta JA}$

$T_A = 94 - (175 - 157) - (0.54)(28)$

$T_A = 61°C$

Solution 2 (using Equation 2)

Steps 1 thru 5 are as Solution 1

Step 6: Find P_F from Figure 19. Read P_F = 3.0 W

Step 7: Compute T_A from $T_A = T_{J(max)} - (P_R + P_F) R_{\theta JA}$

$T_A = 157 - (0.54 + 3) 28$

$T_A = 58°C$

The discrepancy occurs because thermal response is factored into solution 1, and advantage is taken of the cooling time after the power pulse and before reverse voltage achieves its maximum. 61°C is a satisfactory ambient temperature.

FIGURE 12 – REVERSE POWER DISSIPATION, SINE WAVE

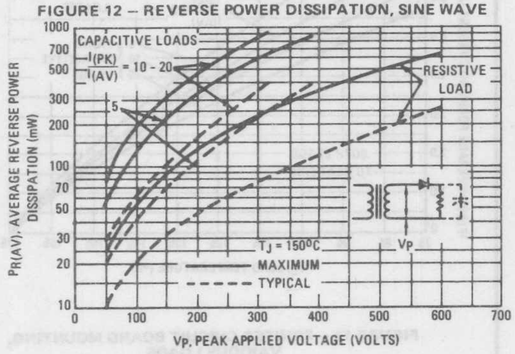


FIGURE 13 – REVERSE POWER DISSIPATION, SQUARE WAVE

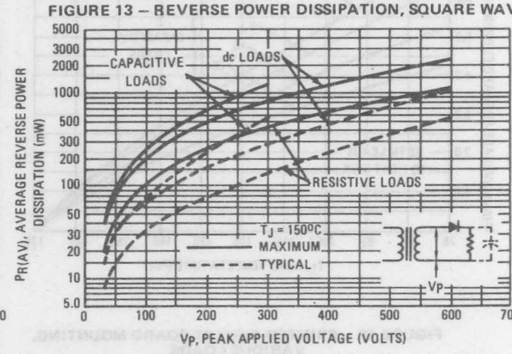


FIGURE 14 – NORMALIZED REVERSE CURRENT

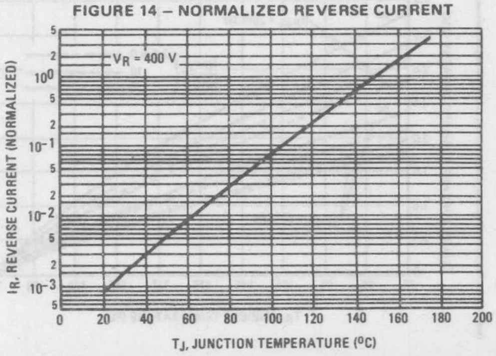
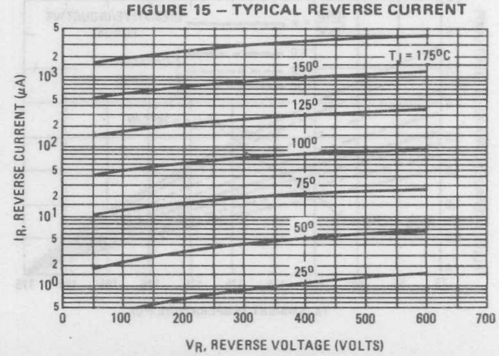


FIGURE 15 – TYPICAL REVERSE CURRENT



STATIC CHARACTERISTICS

FIGURE 16 – FORWARD VOLTAGE

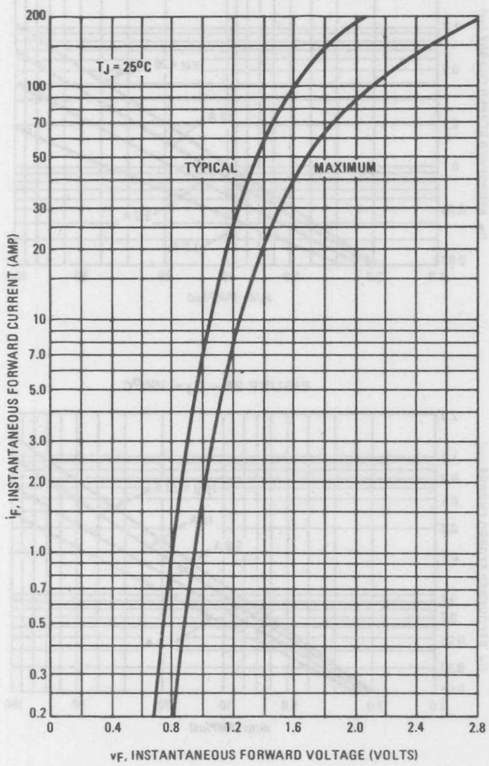


FIGURE 17 – MAXIMUM SURGE CAPABILITY

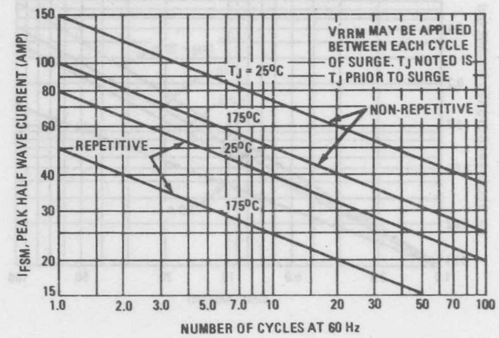
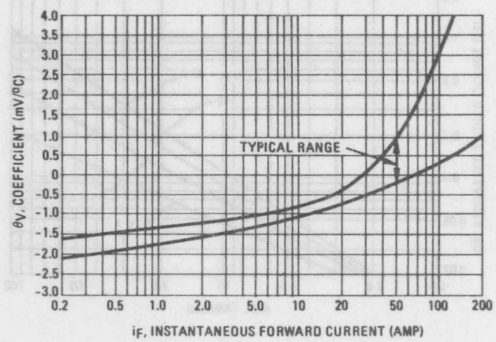
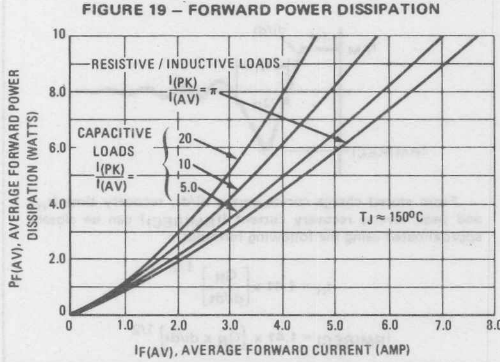


FIGURE 18 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT



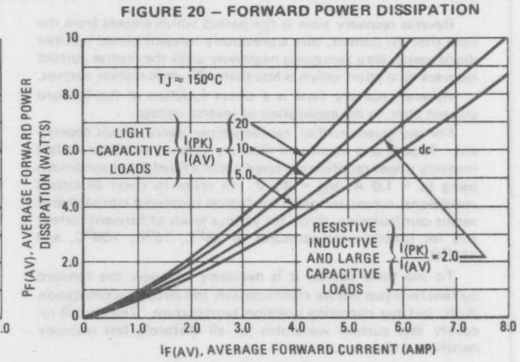
SINE WAVE INPUT

FIGURE 19 – FORWARD POWER DISSIPATION



SQUARE WAVE INPUT

FIGURE 20 – FORWARD POWER DISSIPATION



TYPICAL RECOVERED STORED CHARAGE DATA

(See Note 3)

FIGURE 21 – T_J = 25°C

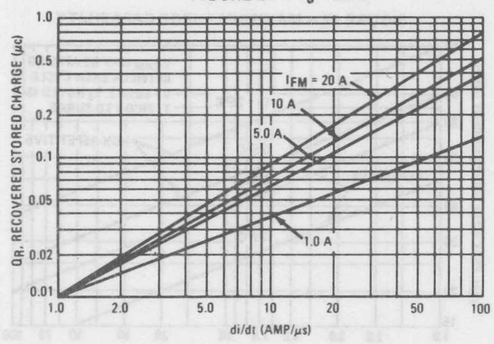


FIGURE 22 – T_J = 75°C

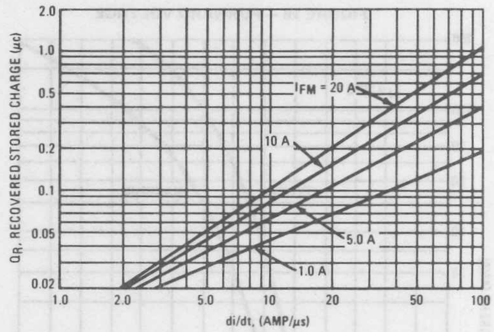


FIGURE 23 – T_J = 100°C

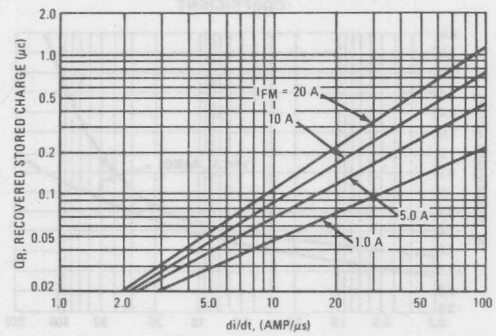
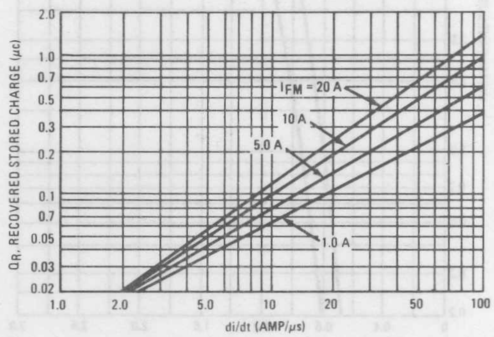


FIGURE 24 – T_J = 150°C



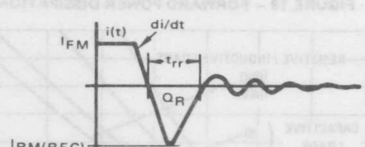
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

DYNAMIC CHARACTERISTICS

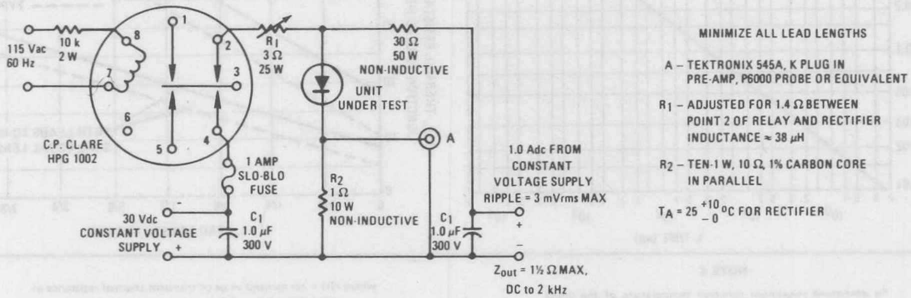


FIGURE 25 – REVERSE RECOVERY CIRCUIT

FIGURE 26 – FORWARD RECOVERY TIME

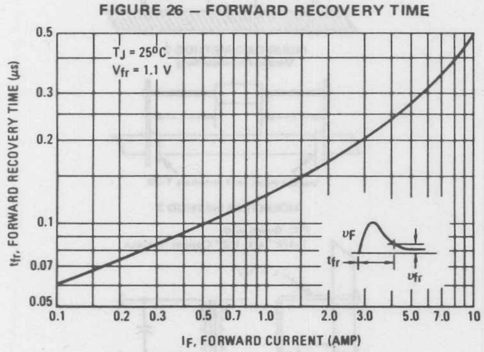


FIGURE 27 – JUNCTION CAPACITANCE

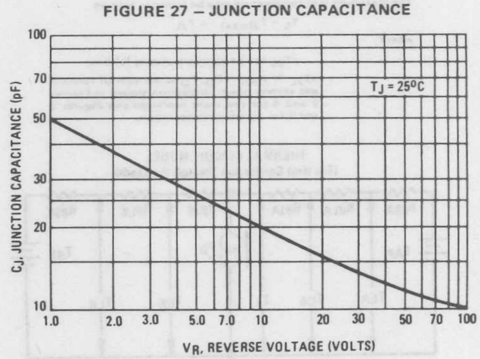


FIGURE 28 – THERMAL RESPONSE

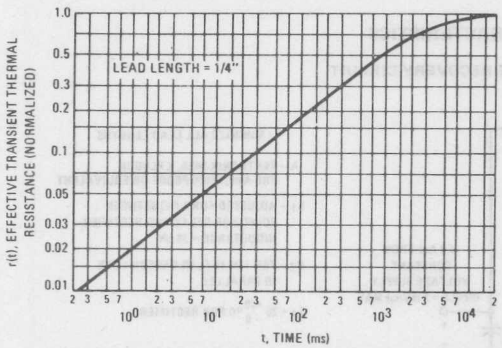
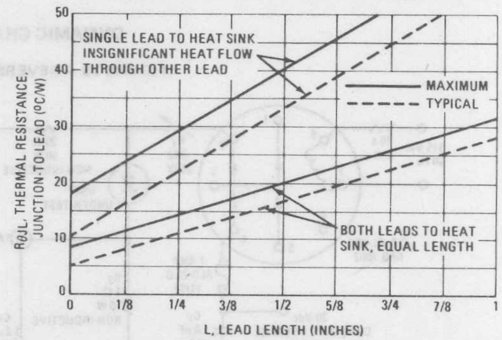


FIGURE 29 – STEADY-STATE THERMAL RESISTANCE



NOTE 4

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

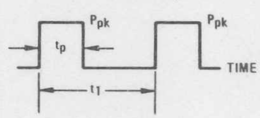
$$T_J = T_L + \Delta T_{JL}$$

where ΔT_{JL} is the increase in junction temperature above the lead temperature. It may be determined by:

$$\Delta T_{JL} = P_{pk} \cdot R_{\theta JL} \, [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where r(t) = normalized value of transient thermal resistance at time t from Figure 28, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.



DUTY CYCLE = t_p/t_1
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

NOTE 5

Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature	$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
T_L = Lead Temperature	$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
T_C = Case Temperature	$R_{\theta J}$ = Thermal Resistance, Junction to Case
T_J = Junction Temperature	P_D = Total Power Dissipation = $P_F + P_R$
	P_F = Forward Power Dissipation
	P_R = Reverse Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.) Values for thermal resistance components are:

$R_{\theta L}$ = 46°C/W/IN. Typically and 48°C/W/IN Maximum.
$R_{\theta J}$ = 10°C/W Typically and 16°C/W Maximum.

The maximum lead temperature may be found as follows:

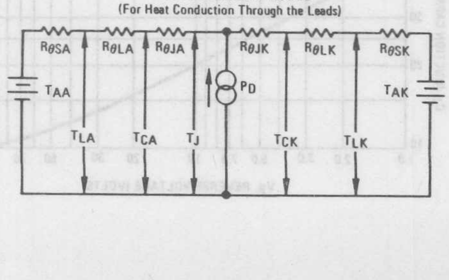
$$T_L = T_{J(max)} - \Delta T_{JL}$$

where

ΔT_{JL} can be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \cdot P_D$; P_D is the sum of forward and reverse power dissipation shown in Figures 2 and 4 for sine wave operation and Figures 3 and 5 for square wave operation.

THERMAL CIRCUIT MODEL
(For Heat Conduction Through the Leads)



NOTE 6

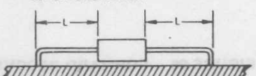
Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

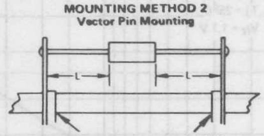
MOUNTING METHOD	LEAD LENGTH, L (IN)				$R_{\theta JA}$
	1/8	1/4	1/2	3/4	
1	50	51	53	55	°C/W
2	58	59	61	63	°C/W
3	28				°C/W

MOUNTING METHOD 1

P.C. Board Where Available Copper Surface area is small.



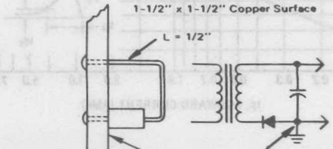
MOUNTING METHOD 2
Vector Pin Mounting



Vector Push-In Terminals T-28

MOUNTING METHOD 3

P.C. Board with
1-1/2" x 1-1/2" Copper Surface



Board Ground Plane

MOTOROLA

BY 406/407

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

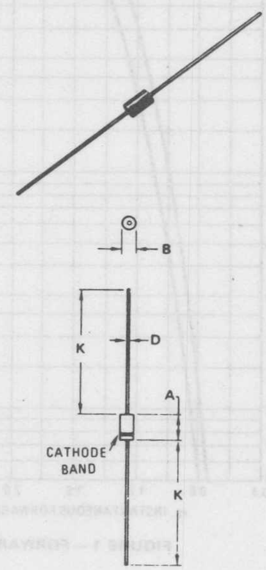
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 200 nanoseconds providing high efficiency at frequencies to 250 Hz.

DESIGNER'S DATA FOR „WORST CASE" CONDITIONS

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves — representing device characteristic boundaries — are given to facilitate „worst case" design.

FAST RECOVERY POWER RECTIFIERS

350/600 VOLTS
0.8 AMPERE



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	-	1.100	-

CASE 59-04

MAXIMUM RATINGS

Ratings	Symbol	BY 406	BY 407	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage	V_{RWM} V_{RRM}	350	600	Volts
DC Blocking Voltage	V_R	300	500	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_A = 75^oC$)	$I_{F(AV)}$	← 0,8 →		Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions) ($T_A = 75^oC$)	I_{FSM}	← 20 →		Amps
Operating Junction Temp. Range	T_J	← -65 to +150 →		^oC
Storage Temperature Range	T_{stg}	← -65 to +175 →		^oC

THERMAL CHARACTERISTICS

Characteristics	Symbol	Max.	Unit
Thermal Resistance, Junction to Ambient (Typical Printed Circuit Board Mounting)	$R_{\theta JA}$	65	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Forward Voltage (I_F = 2,0 Amp. T_A = 25 Grad C)	V_F	—	1,1	1,55	Volts
Reverse Current (rated dc voltage) $T_A = 25^oC$ $T_A = 125^oC$	I_R	— —	1,0 —	2,0 125	μA

REVERSE RECOVERY CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time (I_F = 10 mA to V_R = 50 V	t_{rr}	—	150	300	ns

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded

FINISH: External leads are tin plated, leads are readily solderable

POLARITY: Cathode indicated by Polarity band

WEIGHT: 0.4 Grams (Approximately)

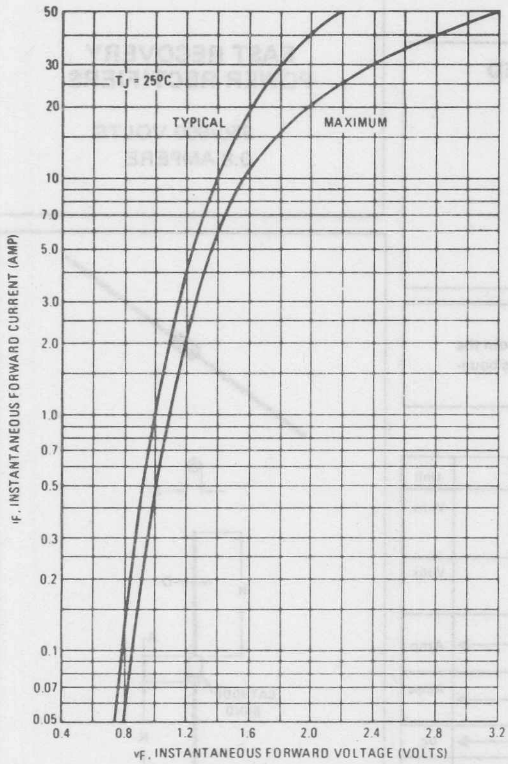


FIGURE 1 – FORWARD VOLTAGE

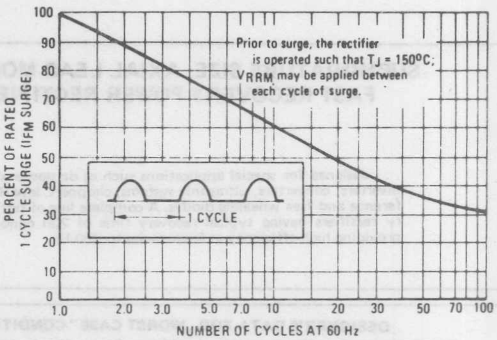


FIGURE 2 – MAXIMUM SURGE CAPABILITY

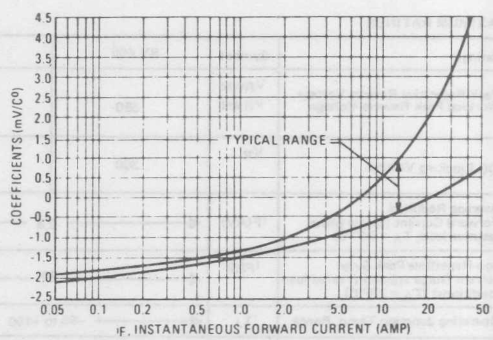


FIGURE 3 – TEMPERATURE COEFFICIENT

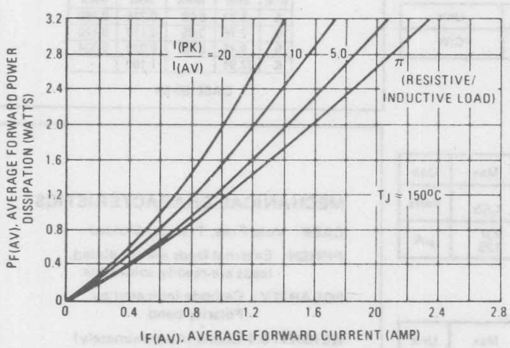


FIGURE 4 – FORWARD POWER DISSIPATION

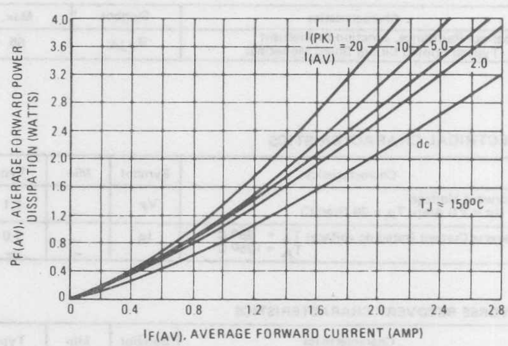


FIGURE 5 – FORWARD POWER DISSIPATION

MAXIMUM CURRENT RATINGS
(SEE NOTES 1 and 2)

SINE WAVE INPUT

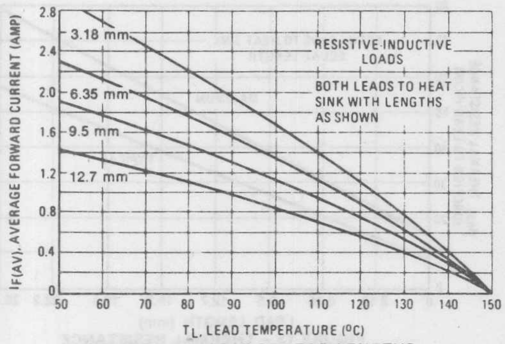


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

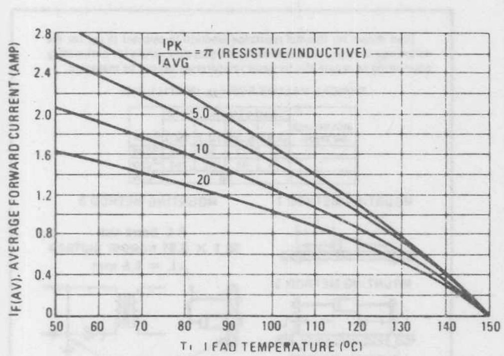


FIGURE 8 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

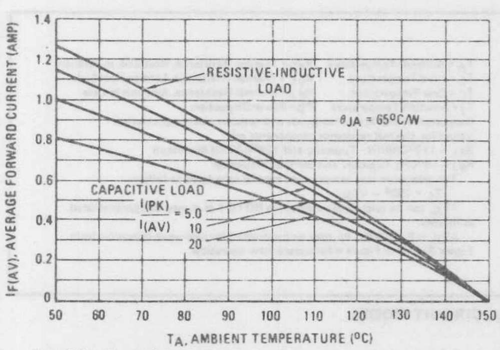


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

SQUARE WAVE INPUT

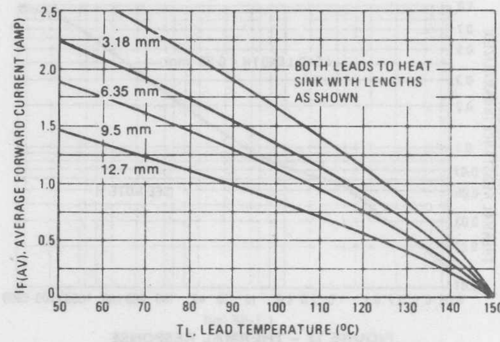


FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

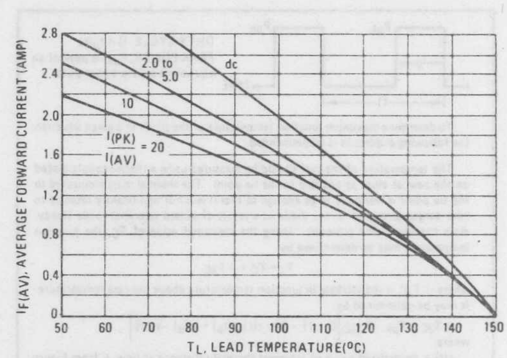


FIGURE 9 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

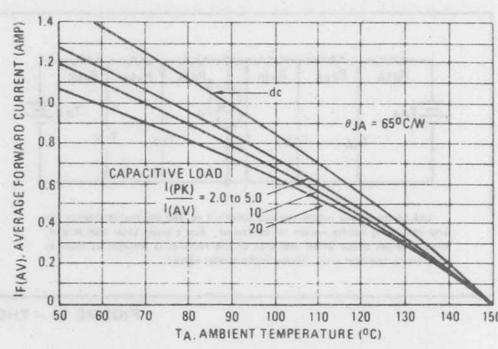


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

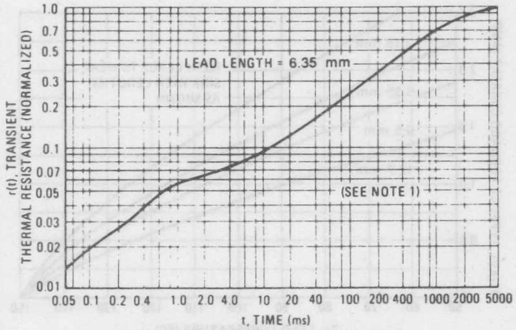


FIGURE 12 – THERMAL RESPONSE

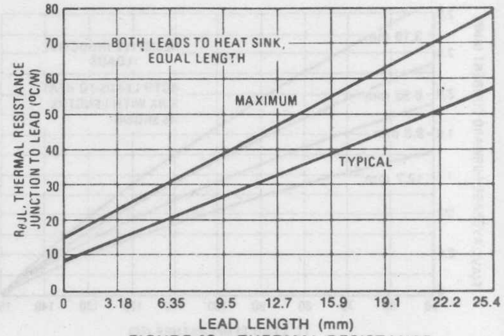
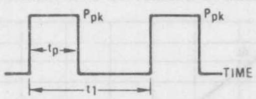


FIGURE 13 – THERMAL RESISTANCE

NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended

The temperature of the case should be measured using a thermocouple placed on the case as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1) \right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 12, i.e.:

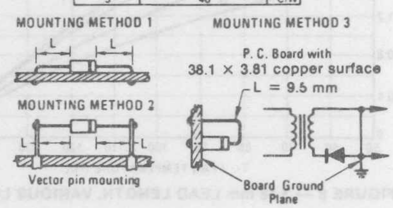
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

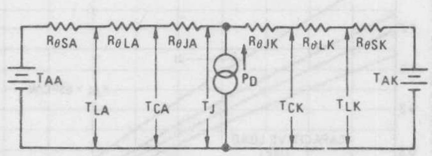
NOTE 2

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L(mm)				$R_{\theta JA}$
	3.81	6.35	12.7	19.1	
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W





Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.)

Values for thermal resistance components are:

$R_{\theta L}$ = 112°C/W/IN. Typically and 128°C/W/IN Maximum
$R_{\theta J}$ = 18°C/W Typically and 30°C/W Maximum

The maximum lead temperature may be calculated as follows:

$$T_L = 150^{\circ} - \Delta T_{JL}$$

ΔT_{JL} can be calculated as shown in NOTE 1 or it may be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \bullet P_F$; P_F may be formulated for sine-wave operation from Figure 3 or from Figure 4 for square-wave operation.

FIGURE 14 – THERMAL CIRCUIT MODEL

TYPICAL DYNAMIC CHARACTERISTICS

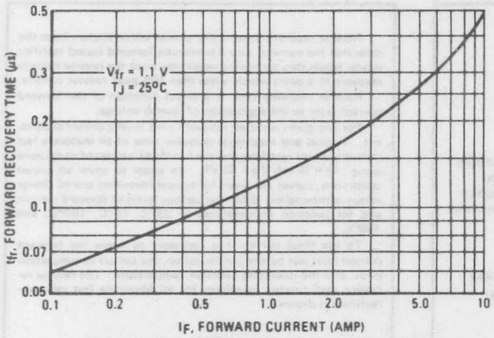


FIGURE 15 – FORWARD RECOVERY TIME

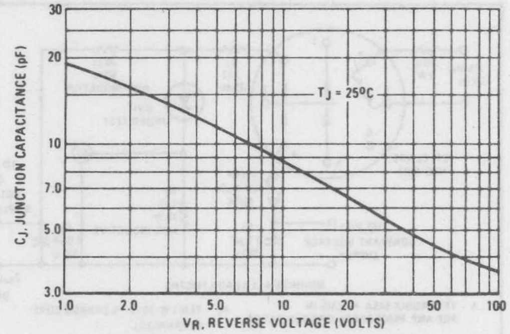


FIGURE 16 – JUNCTION CAPACITANCE

TYPICAL RECOVERED STORED CHARGE DATA
(SEE NOTE 3)

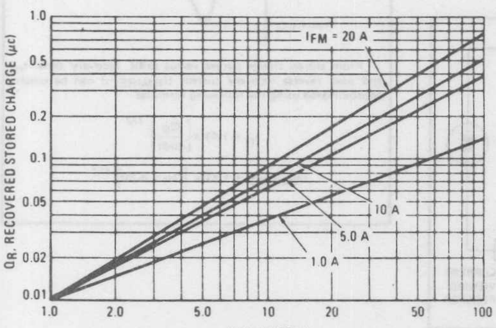


FIGURE 17 – T_J = 25°C

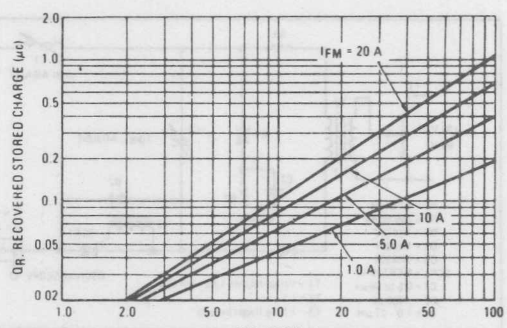


FIGURE 18 – T_J = 75°C

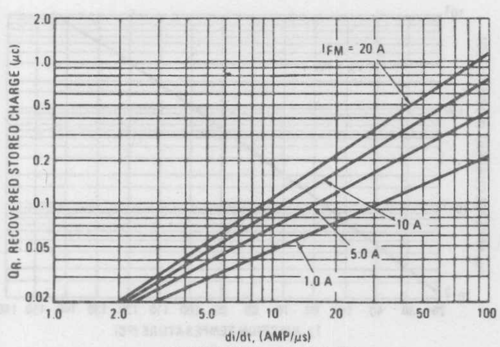


FIGURE 19 – T_J = 100°C

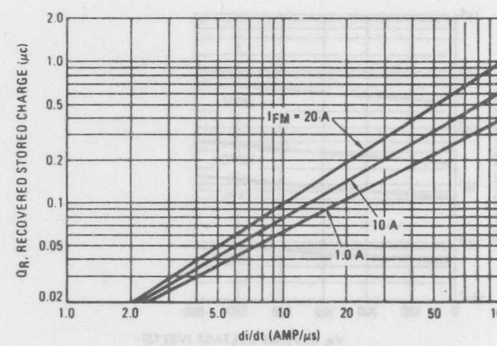


FIGURE 20 – T_J = 150°C

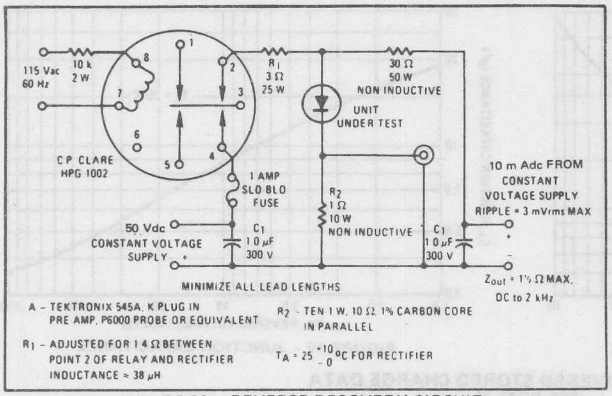


FIGURE 21 – REVERSE RECOVERY CIRCUIT

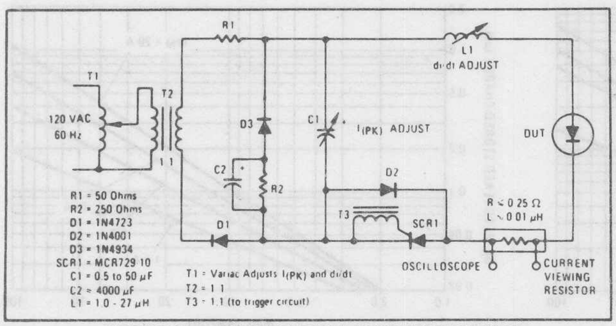


FIGURE 22 – JEDEC REVERSE RECOVERY CIRCUIT

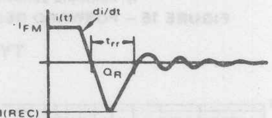
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using $I_F = 10$ mA $V_R = 50$ VR. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

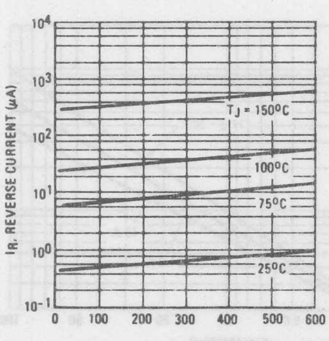


FIGURE 23 – TYPICAL REVERSE LEAKAGE

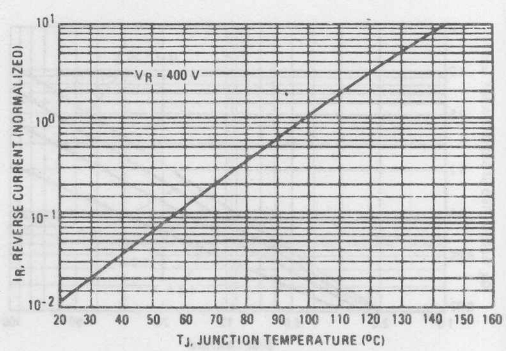


FIGURE 24 – TYPICAL REVERSE LEAKAGE

MOTOROLA

BY 500 SERIES

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

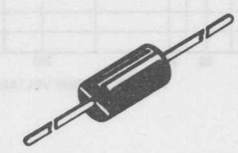
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 100 nanoseconds providing high efficiency at frequencies to 250 kHz.

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

FAST RECOVERY POWER RECTIFIERS

100–600 VOLTS
5 AMPERES



MAXIMUM RATINGS

Rating	Symbol	BY 500–100	BY 500–200	BY 500–400	BY 500–600	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	100	200	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	150	250	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	70	140	280	420	Volts
Average Rectified Forward Current (Single phase resistive load, $T_A = 25^oC$) (1)	I_O	← 5.0 →				Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	← 200 (one cycle) →				Amp
Operating and Storage Junction Temperature Range (2)	T_J, T_{stg}	← -65 to +175 →				^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Recommended Printed Circuit Board Mouting, See Note 6, Page 8)	$R_{\theta JA}$	28	$^oC/W$

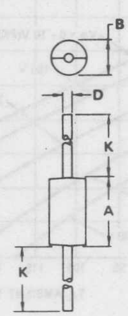
ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Forward Voltage (I_F = 3.0 Amp, $T_J = 25^oC$)	V_F	–	1.04	1.25	Volts
Reverse Current (rated dc voltage) $T_J = 25^oC$	I_R	–	2.0	10	μA
$T_J = 100^oC$				300	

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time (I_F = 1.0 Amp to V_R = 30 Vdc. Figure 25) (I_F = 15 Amp, di/dt = 10 A/μs, Figure 26)	t_{rr}	– –	100 150	200 300	ns
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 25)	$I_{RM(REC)}$	–	–	2.0	Amp

(1) Must be derated for reverse power dissipation. See Note 2, Page 3.
(2) Derate as shown in Figure 1



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	9.65	0.370	0.380
B	4.83	5.33	0.190	0.210
D	1.22	1.32	0.048	0.052
K	26.97	27.23	1.062	1.072

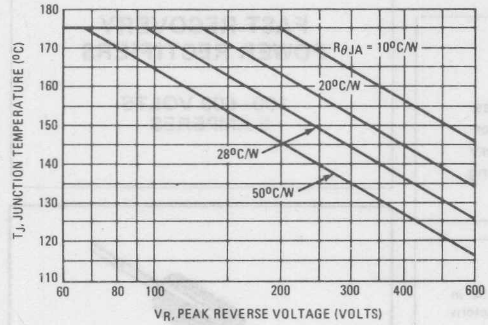
CASE 267-01

MECHANICAL CHARACTERISTICS

Case: Void Free, Transfer Molded
Finish: External Leads are Plated, Leads are readily Solderable
Polarity: Indicated by Cathode Band
Weight: 1.1 Grams (Approximately)
Maximum Lead Temperature for Soldering Purposes:
240°C, 1/8" from case for 10 s at 5.0 lb. tension

MAXIMUM CURRENT AND TEMPERATURE RATINGS

FIGURE 1 – MAXIMUM ALLOWABLE JUNCTION TEMPERATURE



NOTE
MAXIMUM JUNCTION TEMPERATURE DERATING

When operating this rectifier at junction temperatures over 120°C, reverse power dissipation and the possibility of thermal runaway must be considered. The data of Figure 1 is based upon worst case reverse power and should be used to derate $T_{J(max)}$ from its maximum value of 175°C. See Note 2 for additional information on derating for reverse power dissipation.

When current ratings are computed from $T_{J(max)}$ and reverse power dissipation is also included, ratings vary with reverse voltage as shown on Figures 2 thru 5.

RESISTIVE LOAD RATINGS

Printed Circuit Board Mounting – See Note 6, Page 8

FIGURE 2 – SINE WAVE INPUT

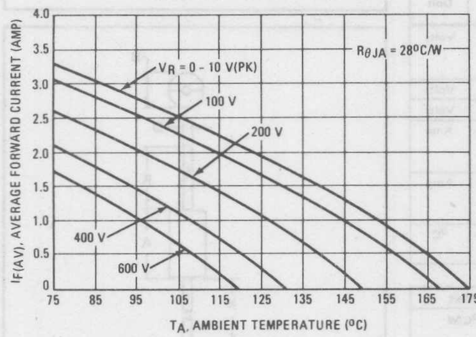


FIGURE 3 – SQUARE WAVE INPUT

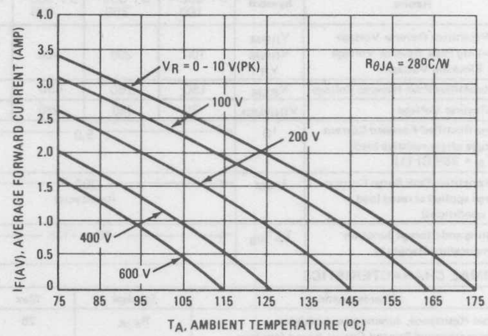


FIGURE 4 – SINE WAVE INPUT

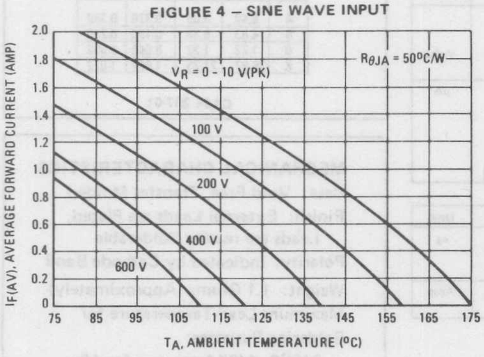
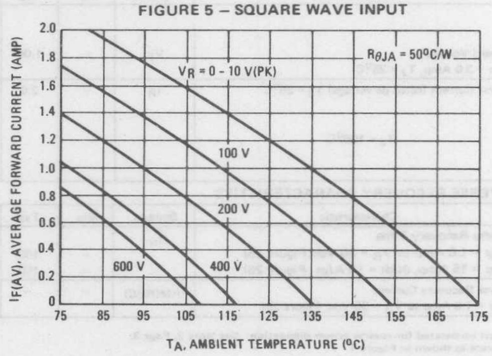


FIGURE 5 – SQUARE WAVE INPUT



MAXIMUM CURRENT RATINGS

Current derating data is based upon the thermal response data of Figure 29 and the forward power dissipation data of Figures 19 and 20. Since reverse power dissipation is not considered in Figures 6 thru 11, additional derating for reverse voltage and for junction to ambient thermal resistance must be applied. See Note 2.

SINE WAVE INPUTS

FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

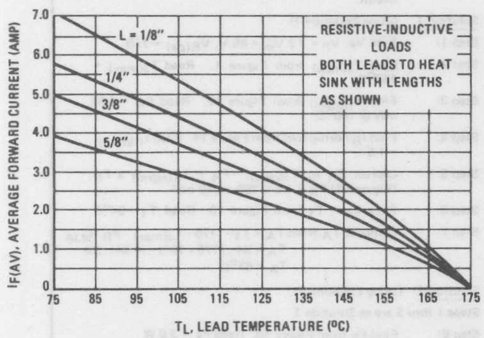


FIGURE 8 – 1/8" LEAD LENGTH, VARIOUS LOADS

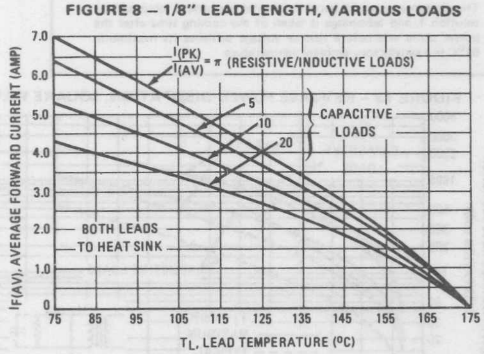
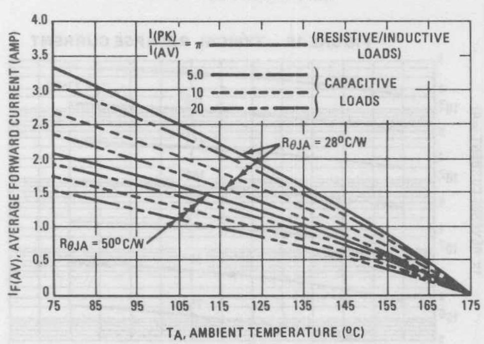


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS



SQUARE WAVE INPUTS

FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

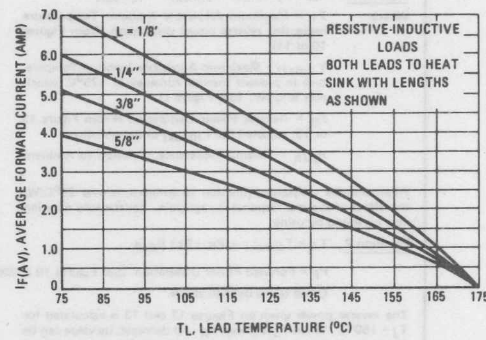


FIGURE 9 – 1/8" LEAD LENGTH, VARIOUS LOADS

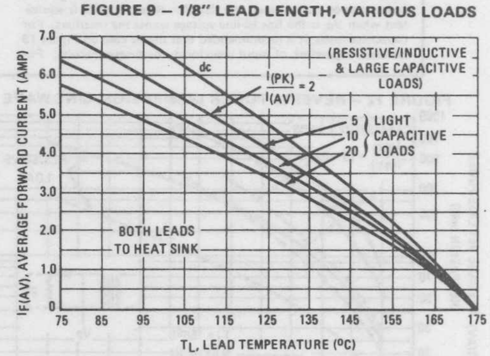
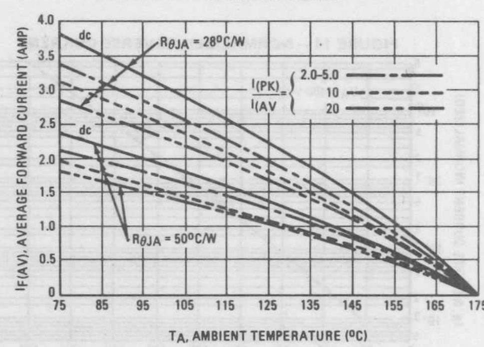


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS



REVERSE POWER DISSIPATION AND CURRENT

NOTE 2
DERATING FOR REVERSE POWER DISSIPATION

In this rectifier, power loss due to reverse current is generally not negligible. For reliable circuit design, the maximum junction temperature must be limited to either 175°C or the temperature which results in thermal runaway. Proper derating may be accomplished by use of equation 1 or equation 2.

Equation 1 $T_A = T_1 - (175 - T_{J(max)}) - P_R R_{\theta JA}$

Where: T_1 = Maximum Allowable Ambient Temperature neglecting reverse power dissipation (from Figures 10 or 11)

$T_{J(max)}$ = Maximum Allowable Junction Temperature to prevent thermal runaway or 175°C, which ever is lower. (See Figure 1).

P_R = Reverse Power Dissipation (From Figure 12 or 13, adjusted for $T_{J(max)}$ as shown below)

$R_{\theta JA}$ = Thermal Resistance, Junction to Ambient.

When thermal resistance, junction to ambient, is over 20°C/W, the effect of thermal response is negligible. Satisfactory derating may be found by using:

Equation 2 $T_A = T_{J(max)} - (P_R + P_F) R_{\theta JA}$

P_F = Forward Power Dissipation (See Figures 19 & 20)

Other terms defined above.

The reverse power given on Figures 12 and 13 is calculated for $T_J = 150°C$. When T_J is lower, P_R will decrease; its value can be found by multiplying P_R by the normalized reverse current from Figure 14 at the temperature of interest.

The reverse power data is calculated for half wave rectification circuits. For full wave rectification using either a bridge or a center-tapped transformer, the data for resistive loads is equivalent when V_P is the line to line voltage across the rectifiers. For capacitive loads, it is recommended that the dc case on Figure 13 be used, regardless of input waveform, for bridge circuits. For capacitively loaded full wave center-tapped circuits, the 20:1 data of Figure 12 should be used for sine wave inputs and the capacitive load data of Figure 13 should be used for square wave inputs regardless of $I_{(pk)}/I_{(av)}$. For these two cases, V_P is the voltage across one leg of the transformer.

Example 1 Find maximum ambient temperature for I_{AV} = 2 A, capacitive load of I_{PK}/I_{AV} = 20, Input Voltage = 60 V (rms), sine wave, $R_{\theta JA}$ = 28°C/W, half wave circuit.

Solution 1 (using Equation 1)

Step 1: Find V_P; $V_P = \sqrt{2}\, V_{in}$ = 85 V, $V_{R(pk)}$ = 170

Step 2: Find $T_{J(max)}$ from Figure 1. Read $T_{J(max)}$ = 157°C

Step 3: Find $P_{R(max)}$ from Figure 12. Read P_R = 360 mW @ 150°C

Step 4: Find I_R normalized from Figure 14. Read $I_{R(norm)}$ = 1.5

Step 5: Correct P_R to $T_{J(max)}$. $P_R = I_{R(norm)} \times P_R$ (Figure 12) P_R = 1.5 x 360 = 540 mW

Step 6: Find $T_A = T_1$ from Figure 10. Read T_1 = 94°C

Step 7: Compute T_A from $T_A = T_1 - (175 - T_{J(max)}) - P_R R_{\theta JA}$
T_A = 94 - (175 - 157) - (0.54) (28)
T_A = 61°C

Solution 2 (using Equation 2)

Steps 1 thru 5 are as Solution 1

Step 6: Find P_F from Figure 19. Read P_F = 3.0 W

Step 7: Compute T_A from $T_A = T_{J(max)} - (P_R + P_F) R_{\theta JA}$
T_A = 157 - (0.54 + 3)28
T_A = 58°C

The discrepancy occurs because thermal response is factored into solution 1, and advantage is taken of the cooling time after the power pulse and before reverse voltage achieves its maximum. 61°C is a satisfactory ambient temperature.

FIGURE 12 – REVERSE POWER DISSIPATION, SINE WAVE

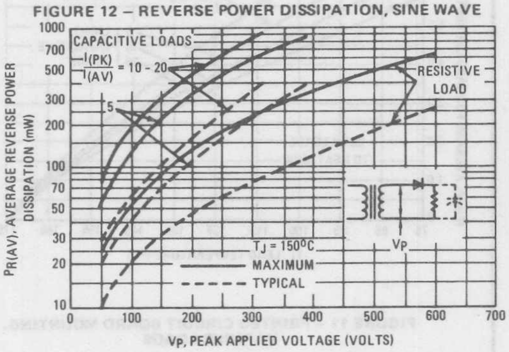


FIGURE 13 – REVERSE POWER DISSIPATION, SQUARE WAVE

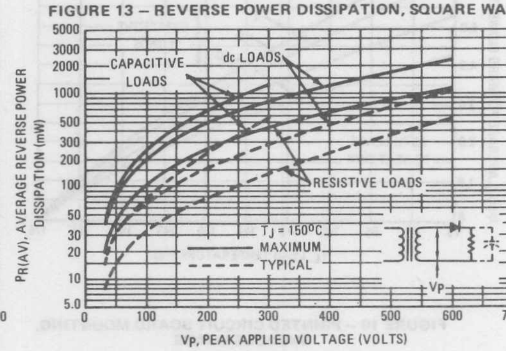


FIGURE 14 – NORMALIZED REVERSE CURRENT

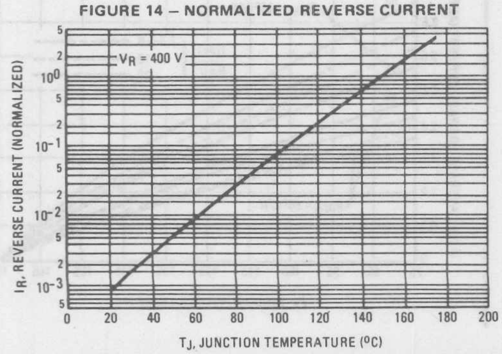
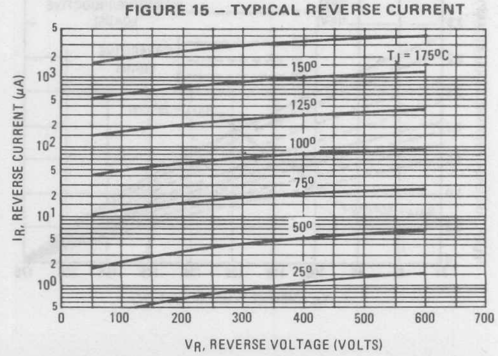


FIGURE 15 – TYPICAL REVERSE CURRENT



STATIC CHARACTERISTICS

FIGURE 16 – FORWARD VOLTAGE

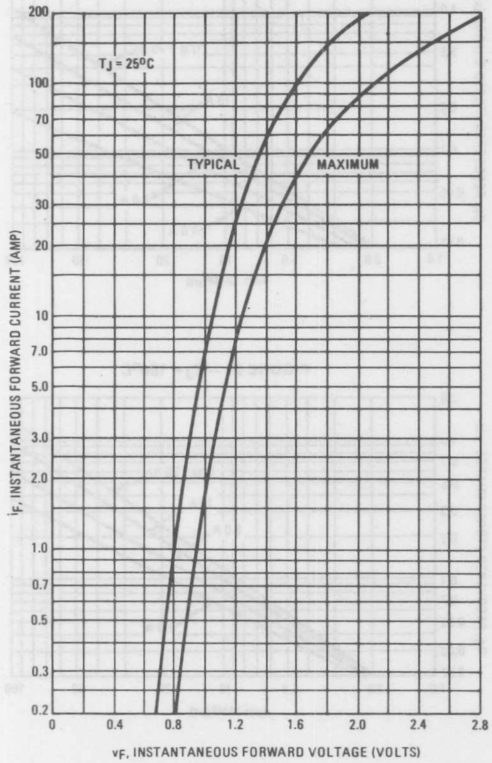


FIGURE 17—MAXIMUM NONREPETITIVE SURGE CURRENT

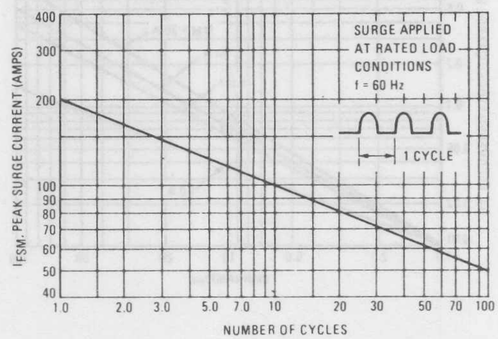
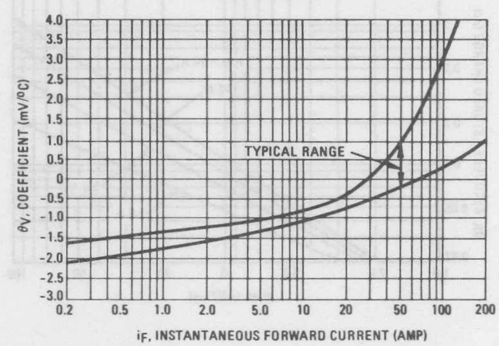
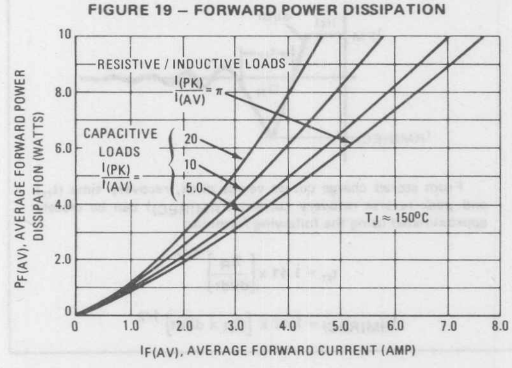


FIGURE 18 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT



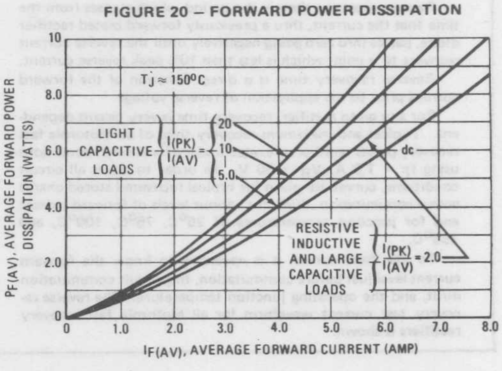
SINE WAVE INPUT

FIGURE 19 – FORWARD POWER DISSIPATION



SQUARE WAVE INPUT

FIGURE 20 – FORWARD POWER DISSIPATION



TYPICAL RECOVERED STORED CHARAGE DATA

(See Note 3)

FIGURE 21 – $T_J = 25^oC$

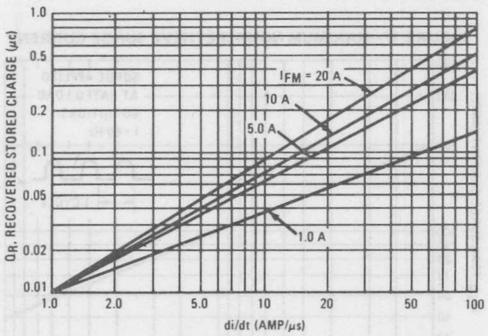


FIGURE 22 – $T_J = 75^oC$

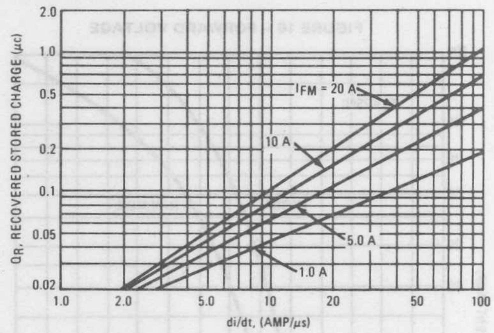


FIGURE 23 – $T_J = 100^oC$

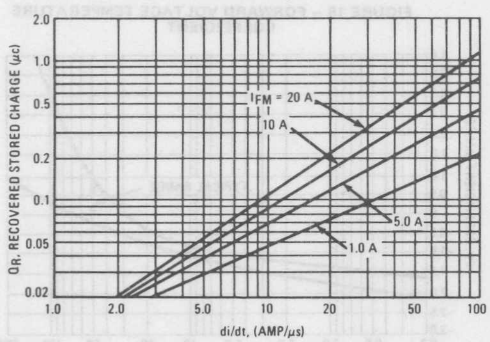
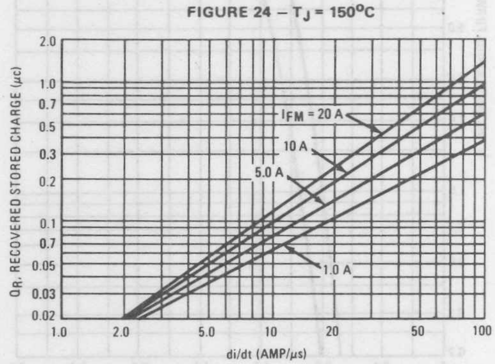


FIGURE 24 – $T_J = 150^oC$



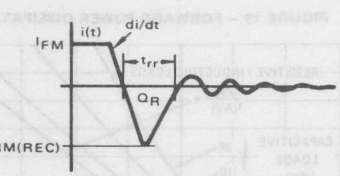
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using $I_F = 1.0$ A, $V_R = 30$ V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



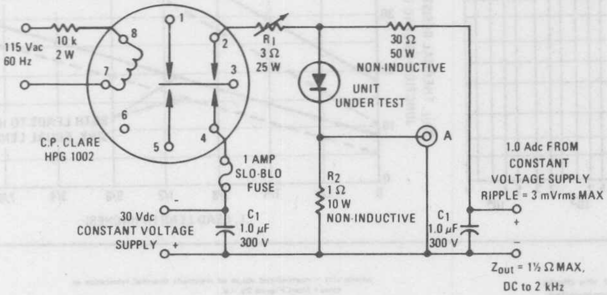
From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

DYNAMIC CHARACTERISTICS

FIGURE 25 – REVERSE RECOVERY CIRCUIT



MINIMIZE ALL LEAD LENGTHS

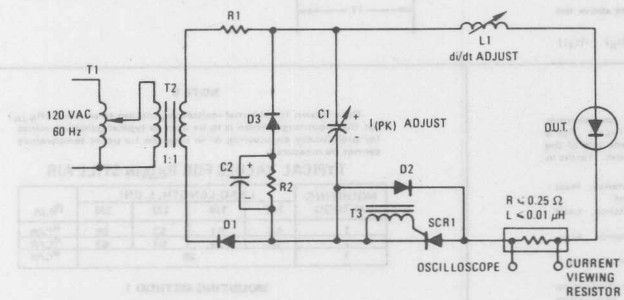
A – TEKTRONIX 545A, K PLUG IN PRE-AMP, P6000 PROBE OR EQUIVALENT

R_1 – ADJUSTED FOR 1.4 Ω BETWEEN POINT 2 OF RELAY AND RECTIFIER INDUCTANCE ≈ 38 μH

R_2 – TEN-1 W, 10 Ω, 1% CARBON CORE IN PARALLEL

$T_A = 25\,^{+10}_{-0}\,^{\circ}C$ FOR RECTIFIER

FIGURE 26 – JEDEC REVERSE RECOVERY CIRCUIT



R1 = 50 Ohms
R2 = 250 Ohms
D1 = 1N4723
D2 = 1N4001
D3 = 1N4934
SCR1 = MCR729-10
C1 = 0.5 to 50 μF
C2 ≈ 4000 μF
L1 = 1.0 - 27 μH
T1 = Variac Adjusts $I_{(PK)}$ and di/dt
T2 = 1:1
T3 = 1:1 (to trigger circuit)

FIGURE 27 – FORWARD RECOVERY TIME

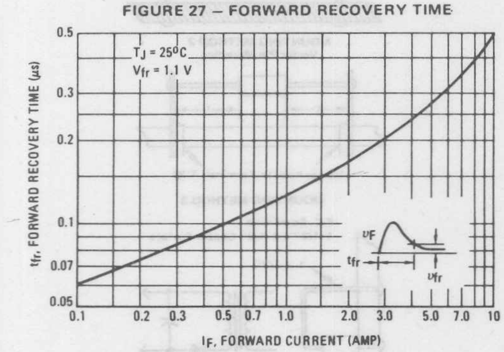


FIGURE 28 – JUNCTION CAPACITANCE

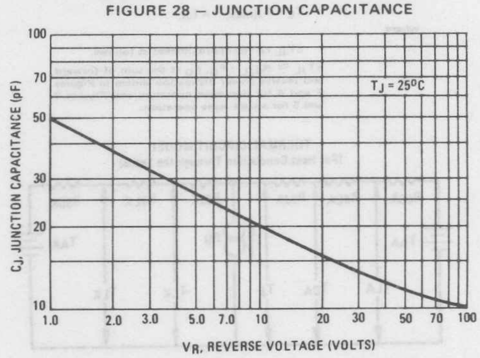


FIGURE 29 – THERMAL RESPONSE

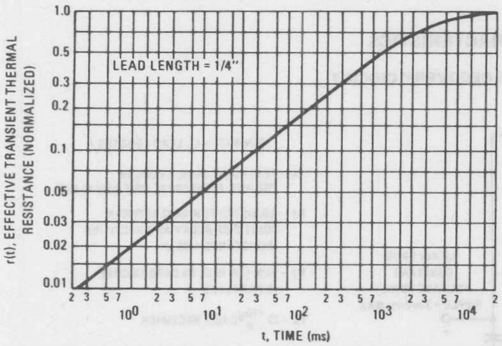
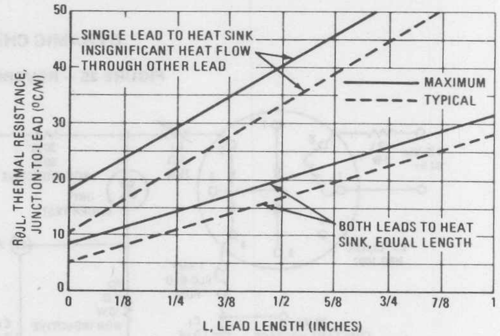


FIGURE 30 – STEADY-STATE THERMAL RESISTANCE



NOTE 4

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

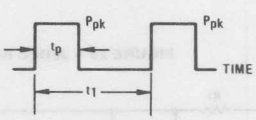
$$T_J = T_L + \Delta T_{JL}$$

where ΔT_{JL} is the increase in junction temperature above the lead temperature. It may be determined by:

$$\Delta T_{JL} = P_{pk} \cdot R_{\theta JL} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1) \right]$$

where $r(t)$ = normalized value of transient thermal resistance at time t from Figure 29, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.



DUTY CYCLE = t_p/t_1
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

NOTE 5

Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature	$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
T_L = Lead Temperature	$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
T_C = Case Temperature	$R_{\theta J}$ = Thermal Resistance, Junction to Case
T_J = Junction Temperature	P_D = Total Power Dissipation = $P_F + P_R$
	P_F = Forward Power Dissipation
	P_R = Reverse Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.) Values for thermal resistance components are:

$R_{\theta L}$ = 46°C/W/IN. Typically and 48°C/W/IN Maximum.
$R_{\theta J}$ = 10°C/W Typically and 16°C/W Maximum.

The maximum lead temperature may be found as follows:

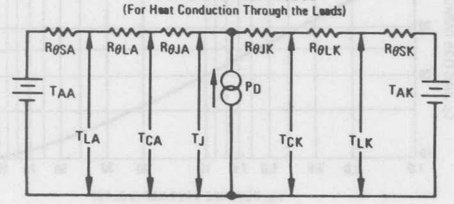
$$T_L = T_{J(max)} - \Delta T_{JL}$$

where

ΔT_{JL} can be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \cdot P_D$; P_D is the sum of forward and reverse power dissipation shown in Figures 2 and 4 for sine wave operation and Figures 3 and 5 for square wave operation.

THERMAL CIRCUIT MODEL
(For Heat Conduction Through the Leads)



NOTE 6

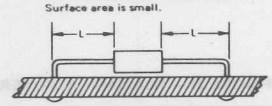
Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

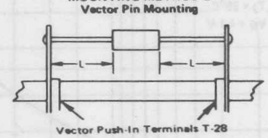
MOUNTING METHOD	LEAD LENGTH, L (IN)				$R_{\theta JA}$
	1/8	1/4	1/2	3/4	
1	50	51	53	55	°C/W
2	58	59	61	63	°C/W
3	28				°C/W

MOUNTING METHOD 1

P.C. Board Where Available Copper Surface area is small.



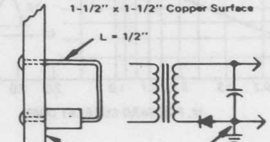
MOUNTING METHOD 2
Vector Pin Mounting



Vector Push-In Terminals T-28

MOUNTING METHOD 3

P.C. Board with
1-1/2" x 1-1/2" Copper Surface



Board Ground Plane

MOTOROLA

BY 601 thru BY 608 SERIES

"SURMETIC" RECTIFIERS

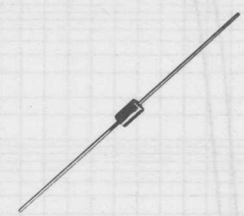
. . . subminiature size, axial lead mounted rectifiers for general-purpose main rectifier applications in TV/HiFi sets and domestic appliances.

Designers Data for "Worst Case" Conditions

The Designers Data Sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

LEAD MOUNTED SILICON RECTIFIERS

50–1250 VOLTS
DIFFUSED JUNCTION

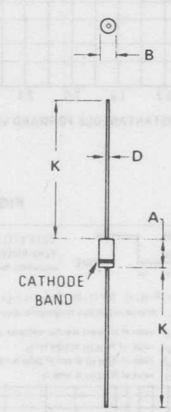


MAXIMUM RATINGS

Rating	Symbol	BY601	BY602	BY603	BY604	BY605	BY606	BY607	BY608	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	1250	Volts
Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 50 Hz)	V_{RSM}	60	120	240	480	720	1000	1200	1500	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	850	Volts
Average Rectified Forward Current (single phase, resistive load, 50 Hz, see Figure 8, $T_A = 75$ °C)	I_O	1.5								Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions, see Figure 2)	I_{FSM}	50 (for 1 cycle)								Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–65 to +175								°C

ELECTRICAL CHARACTERISTICS

Characteristic and Conditions	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop (I_F = 1.5 Amp, T_J = 25 °C) Figure 1	V_F	1.0	1.15	Volts
Maximum Reverse Current (rated dc voltage)	I_R			μA
T_J = 25 °C		0.05	10	
T_J = 100 °C		1.0	50	



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94		1.100	–

CASE 59-04
Does Not Conform to DO-41 Outline.

MECHANICAL CHARACTERISTICS

CASE: Void free, Transfer Molded.
MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 350 °C, 1.27 cm from case for 10 seconds at 2.27 kg tension.
FINISH: All external surfaces are corrosion-resistant, leads are readily solderable.
POLARITY: Cathode indicated by color band.
WEIGHT: 0.40 Grams (approximately).

FIGURE 1 – FORWARD VOLTAGE

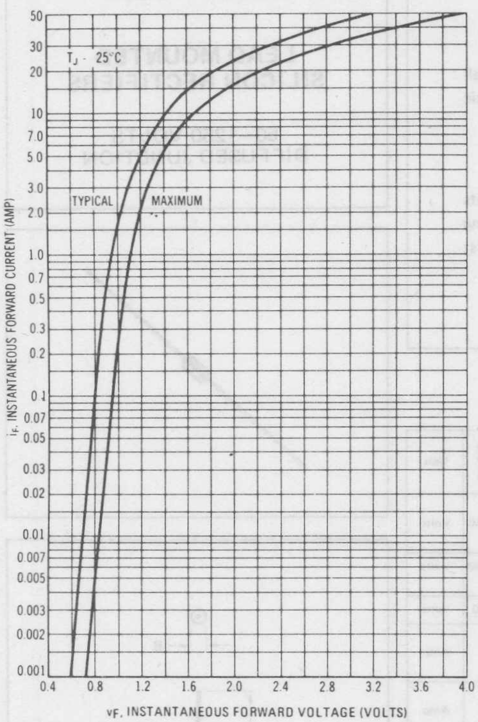


FIGURE 2 – NON REPETITIVE SURGE CAPABILITY

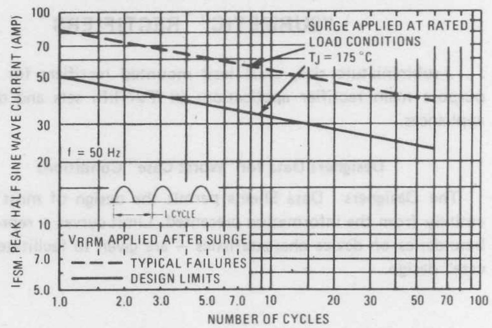


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

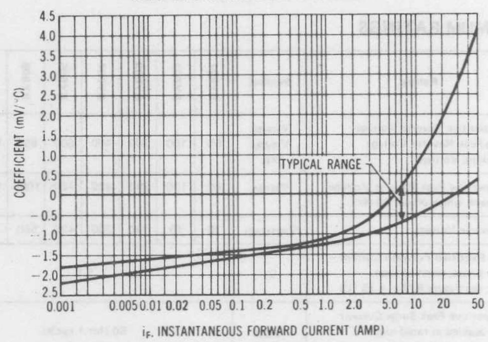
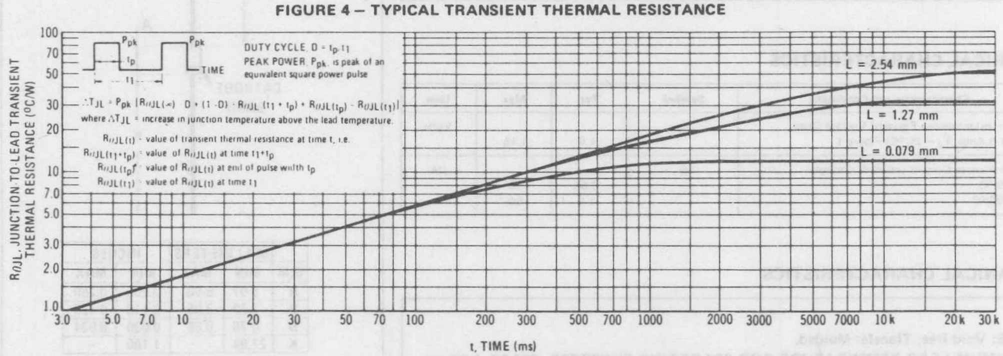


FIGURE 4 – TYPICAL TRANSIENT THERMAL RESISTANCE



The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

$$T_J = T_L + \Delta T_{JL}$$

CURRENT DERATING DATA

FIGURE 5 – FORWARD POWER DISSIPATION

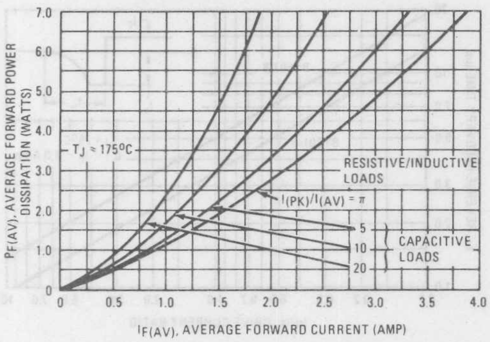


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

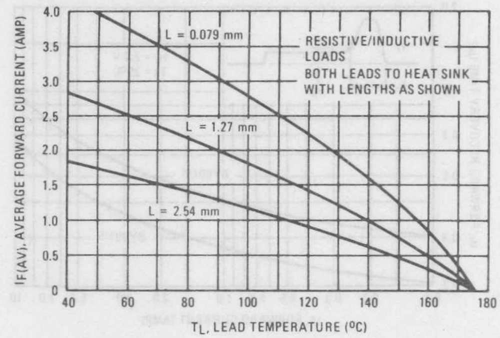


FIGURE 7 – 1.27 mm LEAD LENGTH, VARIOUS LOADS

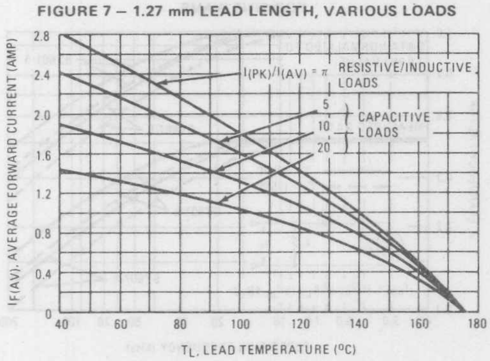


FIGURE 8 – PRINTED CIRCUIT BOARD MOUNTING VARIOUS LOADS

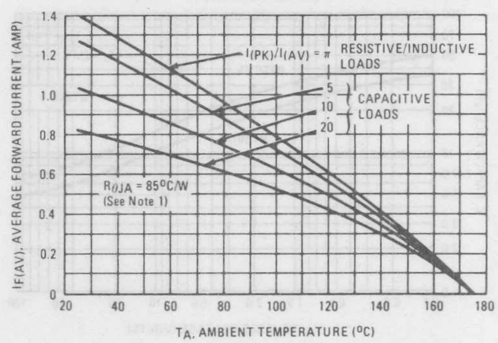
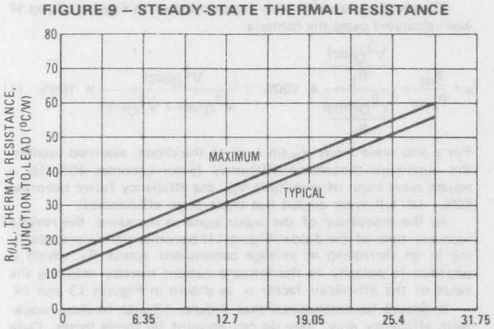


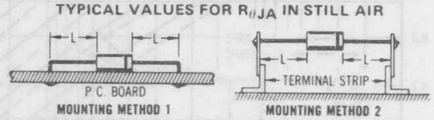
FIGURE 9 – STEADY-STATE THERMAL RESISTANCE



NOTE 1

Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR



MOUNTING METHOD	LEAD LENGTH (cm)			$R_{\theta JA}$
	0.079	1.27	2.54	
1	—	75	85	C/W
2	55	72	85	C/W

TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 10 – FORWARD RECOVERY TIME

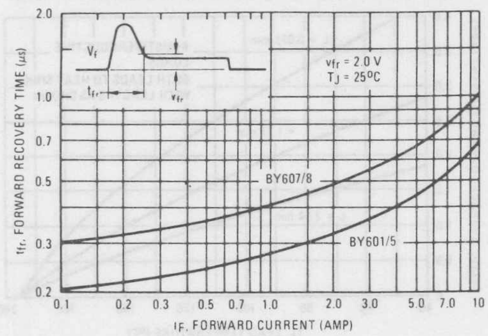


FIGURE 11 – REVERSE RECOVERY TIME

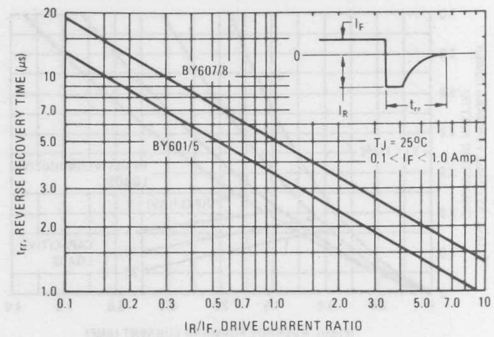


FIGURE 12 – JUNCTION CAPACITANCE

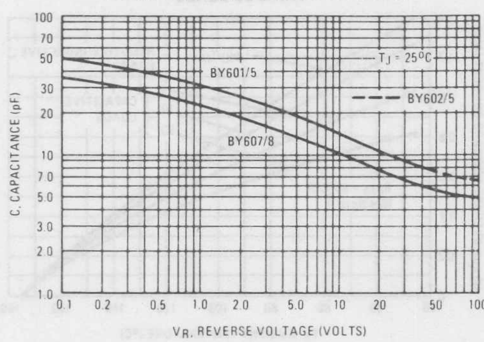


FIGURE 13 – RECTIFICATION WAVEFORM EFFICIENT FOR SINE WAVE

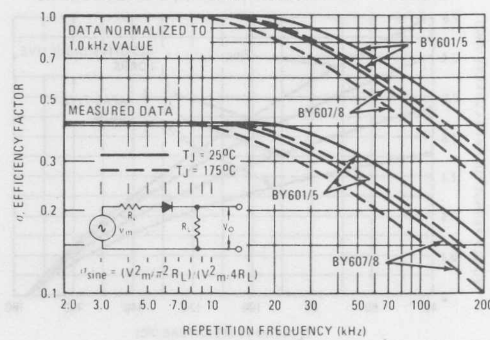
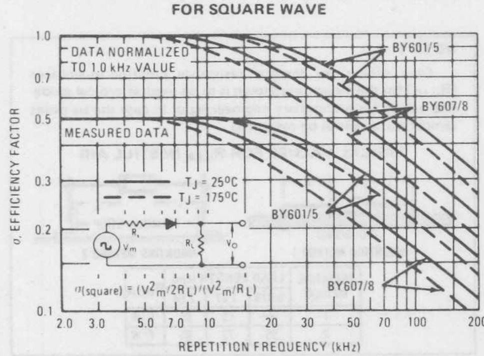


FIGURE 14 – RECTIFICATION WAVEFORM EFFICIENCY FOR SQUARE WAVE



RECTIFIER EFFICIENCY NOTE

The rectification efficiency factor σ shown in Figures 13 and 14 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\dfrac{V^2_{O(dc)}}{R_L}}{\dfrac{V^2_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2_{O(dc)}}{V^2_{O(ac)} + V^2_{O(dc)}} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assumed lossless, the maximum theoretical efficiency factor becomes 40%; for a square wave input of amplitude V_m, the efficiency factor becomes 50%. (A full wave circuit has twice these efficiencies).

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 11) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current thereby reducing the value of the efficiency factor σ, as shown in Figures 13 and 14.

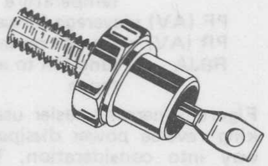
It should be emphasized that Figures 13 and 14 show waveform efficiency only; they do not account for diode losses. Data was obtained by measuring the ac component of V_O with a true rms voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for the Figures.

MOTOROLA

BYS 35 SERIES

SCHOTTKY BARRIER RECTIFIERS

35 AMPERES
20 to 50 VOLTS

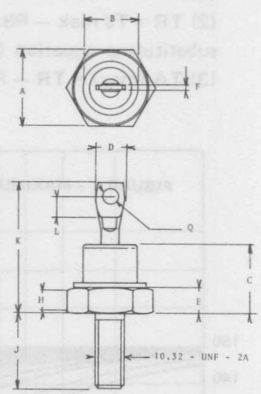


ADVANCE INFORMATION

Switchmode Power Rectifiers

Epitaxial construction with oxyde passivation and metal overlap contact — ion implanted guard ring for transient voltage protection

- lowest combined power losses
- high surge capability
- majority carrier conduction



DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

Do 4
Case 56—02

MAXIMUM RATINGS

Rating	Symbol	BYS35 −20	BYS35 −30	BYS35 −45	BYS35 −50	Units
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	45	50	Volts
Average Rectified Forward Current, Rated V_R Square Wave	$I_{F(AV)}$	35 (T_C = 100° C)		35 (T_C = 90° C)		Amp.
Non-Repetitive Peak Surge Current, 10 mS	I_{FSM}	← 600 →				Amp.
Operating and Storage Junction Temperature	T_J, T_{STG}	← −65 to +150 →				°C
Peak Operating Junction Temperature	T_J (PK)	← 175 →				°C
Voltage Rate of Change	dv/dT	← 1000 →				Volts/µ Sec.

THERMAL CHARACTERISTICS

Characteristics	Symbol	Typ	Max.	Unit
Thermal Resistance Jonction to case	$R_{\theta jc}$	1.2	1.5	°C/W

ELECTRICAL CHARACTERISTICS

Characteristics	Symbol	Typ	Max.	Units
Instantaneous Forward Voltage I_F = 35 Amp. T_C = 25° C T_C = 100° C T_C = 150° C I_F = 70 Amp. T_C = 25° C T_C = 100° C T_C = 150° C	V_F	 0.55 0.48 0.45 0.70 0.62 0.57	 0.63 0.60 — 0.80 0.77 —	Volts
Instantaneous Reverse Current, Rated V_R T_C = 25° C BYS35–20/30 BYS35–45/50	I_R	 70 100	 700 1000	µA
T_C = 100° C BYS35–20/30 BYS35–45/50		8 12	15 25	mA

Minimum Reverse Breakdown Voltage I_{BR} = 10 mA, T_C = 25° C	V_{BR}	30	40	47	53	Volts

MECHANICAL CHARACTERISTICS

CASE: welded, hermetically sealed
POLATITY: cathode to case
MOUNTING POSITIONS: any
STUD TORQUE: 15 in. lb. max.

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be covered when operating this rectifier at reverse voltages above 0,2 VRWM. Proper operating may be accomplished by use of equation:

(1) TA (max) = TJ max − RθJA.PF (AV) − RθJA (AV)

where:

- TA (max) = maximum allowable ambient temperature
- TJ (max) = maximum allowable junction temperature
- PF (AV) = average forward power dissipation
- PR (AV) = average reverse power dissipation
- RθJA = junction to ambient thermal resistance

Figure 1 permits easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figure solves for a reference temperature as determined by equation (2):

(2) TR = TJ max − RθJA PR (AV)

substituting equation (2) into equation (1) yields:

(3) TA (max) = TR − RθJA RF (AV)

HOW TO USE FIG. 1 TO FIND TR (MAX)

Example: find TA (max) for BYS 35−30 operated in a 5 volts/12 A flyback convertor, 6 min = 0,5, VRRM = 12 volts and RθJA = 5^{o} C/W.

STEP 1

Find VR equivalent = VRRM $\sqrt{8}$ = 12 $\sqrt{0,5}$ = 8,5 V.

STEP 2

Find TR from fig. 1 horizontaly intercept VR = 8,5 V with the BYS 35−30 curve. Vertically intercept this point with the RθJA = 5^{o} C/W curve. Read TR directly, TR = 142^{o} C.

STEP 3

Find PF (AV) from figure 3. Read PF (AV) = 6 W.

STEP 4

Find TA (max) from equation (3)

TA max = TR − RθJA. PF (AV)
= 142^{o} C−30^{o} C
= 112^{o} C

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE

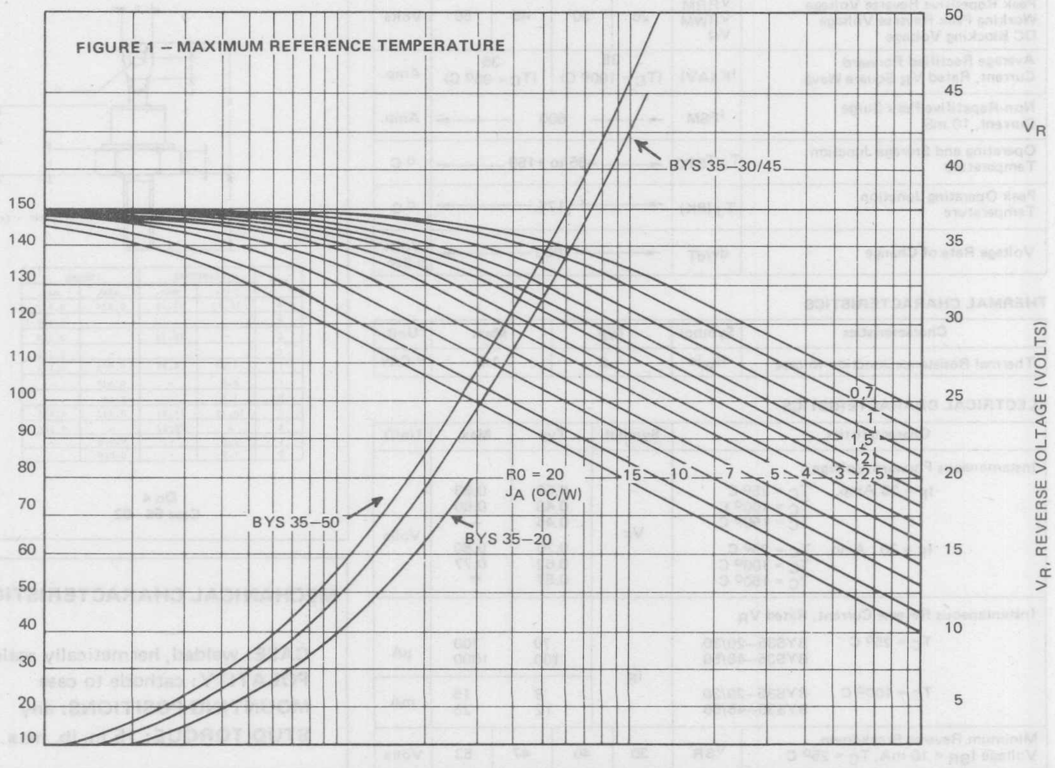
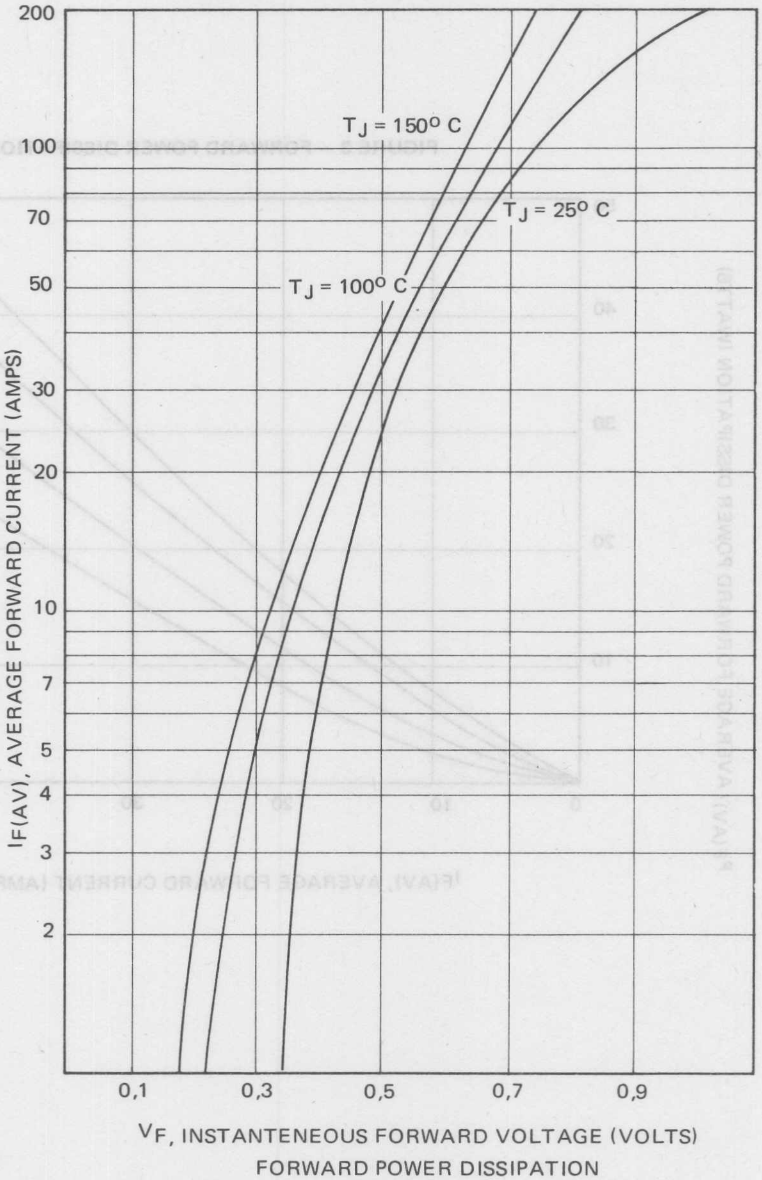
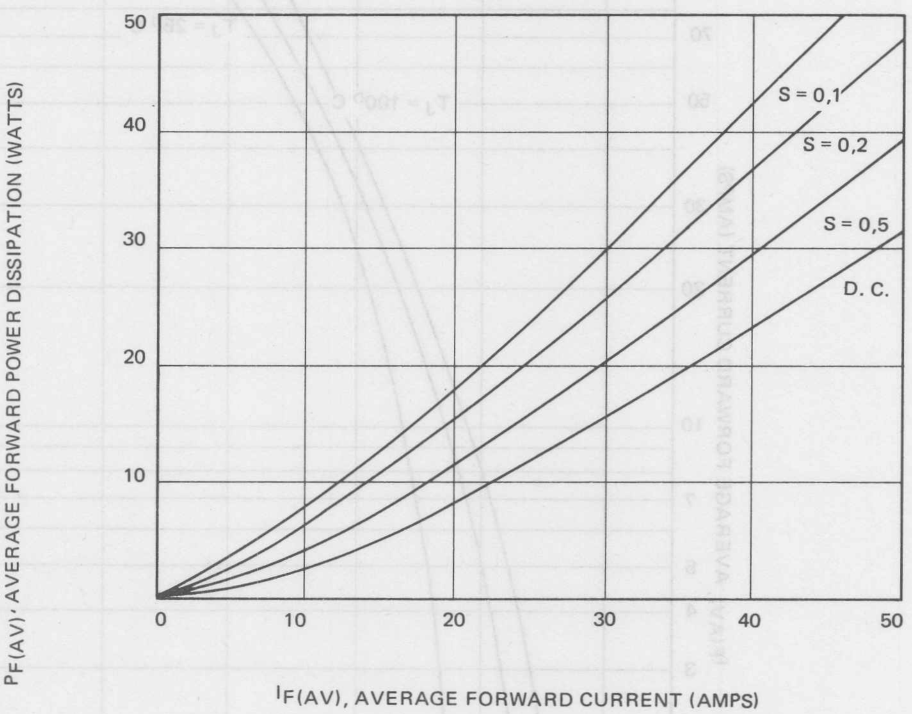


FIGURE 2 – TYPICAL FORWARD VOLTAGE



FORWARD POWER DISSIPATION

FIGURE 3 – FORWARD POWER DISSIPATION



MOTOROLA

BYS 60 SERIES

ADVANCE INFORMATION

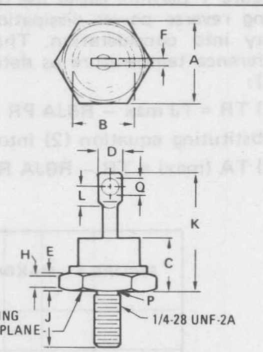
SCHOTTKY BARRIER RECTIFIERS

60 AMPERES
20 to 50 VOLTS

Switchmode Power Rectifiers

Epitaxial construction with oxyde passivation and metal overlap contact – ion implanted guard ring for transient voltage protection

- lowest combined power losses
- high surge capability
- majority carrier conduction



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.96	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

MAXIMUM RATINGS

Rating	Symbol	BYS60 –20	BYS60 –30	BYS60 –45	BYS60 –50	Units
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	45	50	Volts
Average Rectified Forward Current, Rated V_R Square Wave	$I_{F\,(AV)}$	60 ($T_C = 100^o$ C)		60 ($T_C = 90^o$ C)		Amp.
Non-Repetitive Peak Surge Current, 10 mS	I_{FSM}	← 800 (for 1 cycle) →				Amp.
Operating and Storage Junction Temperature	T_J, T_{STG}	← –65 to +150 →				^{o} C
Peak Operating Junction Temperature	T_J (PK)	← 175 →				^{o} C
Voltage Rate of Change	dv/dT	← 1000 →				Volts/μ Sec.

THERMAL CHARACTERISTICS

Characteristics	Symbol	Typ	Max.	Unit
Thermal Resistance Jonction to case	R_{θ} jc	0,7	0,9	^{o} C/W

ELECTRICAL CHARACTERISTICS

Characteristics			Symbol	Typ	Max.	Units
Instantaneous Forward Voltage						
	I_F = 60 Amp.	$T_C = 25^o$ C $T_C = 100^o$ C $T_C = 150^o$ C	V_F	0,65 0,60 0,55	0,70 0,68 –	Volts
	I_F = 120 Amp.	$T_C = 25^o$ C $T_C = 100^o$ C $T_C = 150^o$ C	V_F	0,79 0,74 0,68	0,86 0,81 –	Volts
Instantaneous Reverse Current, Rated V_R						
	$T_C = 25^o$ C	BYS 60–20/30 BYS 60–45/50	I_R	70 100	700 1000	μA
	$T_C = 100^o$ C	BYS 60–20/30 BYS 60–45/50	I_R	8 12	15 25	mA

Characteristics	Symbol	BYS60 –20	BYS60 –30	BYS60 –45	BYS60 –50	Units
Minimum Reverse Breakdown Voltage (R 10 mA, $T_C = 25^o$ C	V_{BR}	30	40	47	53	Volts

MECHANICAL CHARACTERISTICS

CASE: welded, hermetically sealed
POLATITY: cathode to case
MOUNTING POSITIONS: any
STUD TORQUE: 25 in. lb. max.

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be covered when operating this rectifier at reverse voltages above 0,2 VRWM. Proper operating may be accomplished by use of equation:

(1) TA (max) = TJ max − RθJA.PF (AV) − RθJA (AV)

where:

- TA (max) = maximum allowable ambient temperature
- TJ (max) = maximum allowable junction temperature
- PF (AV) = average forward power dissipation
- PR (AV) = average reverse power dissipation
- RθJA = junction to ambient thermal resistance

Figure 1 permits easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figure solves for a reference temperature as determined by equation (2):

(2) TR = TJ max − RθJA PR (AV)

substituting equation (2) into equation (1) yields:

(3) TA (max) = TR − RθJA RF (AV)

HOW TO USE FIG. 1 TO FIND TR (MAX)

Example:
Find TA (max) for BYS 60−30 operated in a 5 V/40 A forward converter as free wheel diode, 6 min = 0,35,VRRM = 17 V and RθJA = 5^o C/W.

STEP 1

Find VR equivalent = VRRM $\sqrt{3}$ min = 17 $\sqrt{0,35}$ = 10 V.

STEP 2

Find TR from fig. 1 horizontaly intercept VR = 10 V with the BYS 60−30 curve. Vertically intercept this point with the RθJA = 5^o C/W curve. Read TR directly, TR = 141^o C.

STEP 3

Find PF (AV) from fig. 3 (IF (AV) in the free wheel diode is:
Io. (1 −5 min) = 26 A). Read PF (AV) = 16 W.

STEP 4

Find TA (max) from equation (3)
TA max = TR − RθJA. PF (AV)
= 141^o C−80^o C = 61^o C

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE

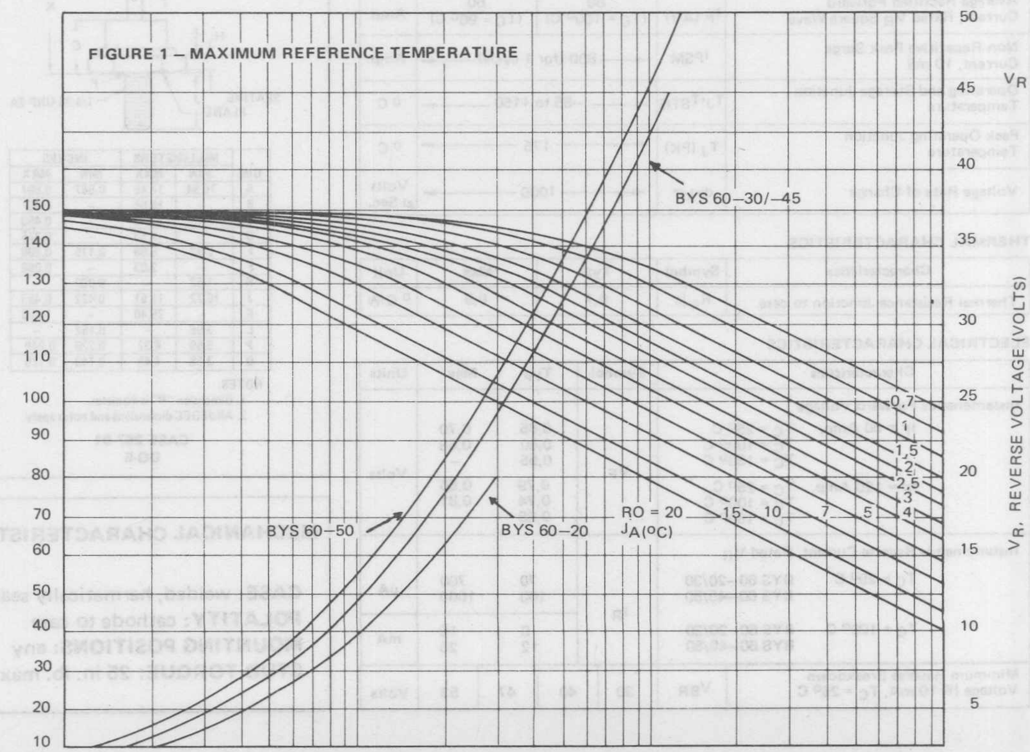


FIGURE 2 – TYPICAL FORWARD VOLTAGE

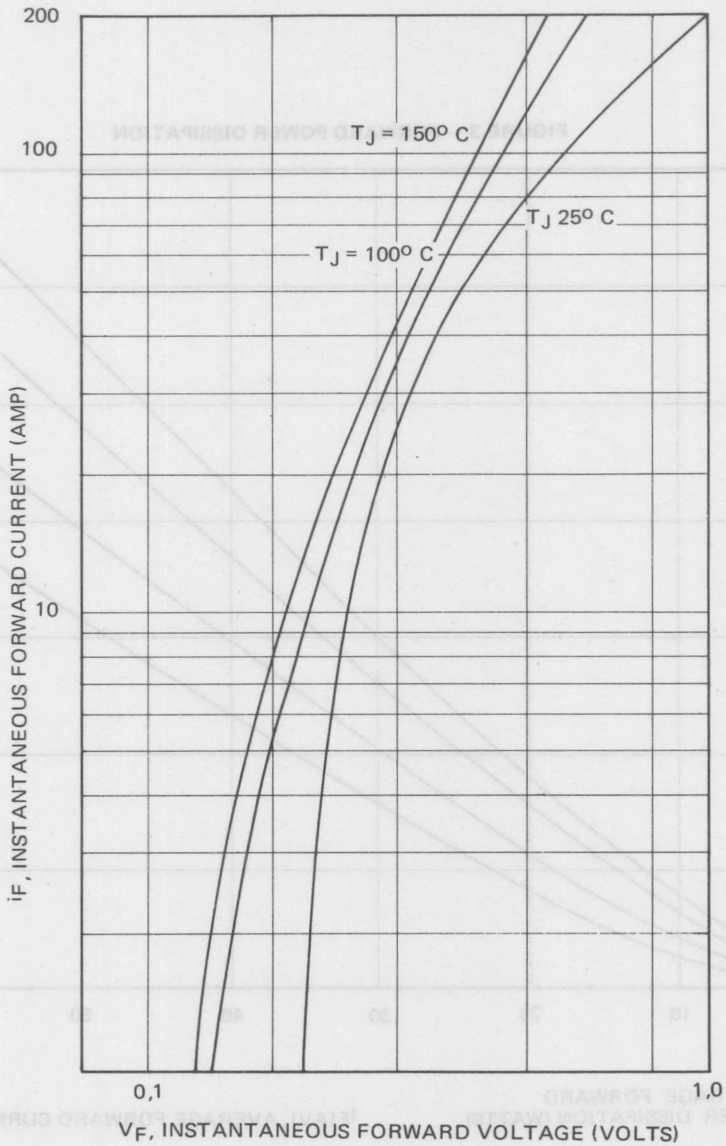
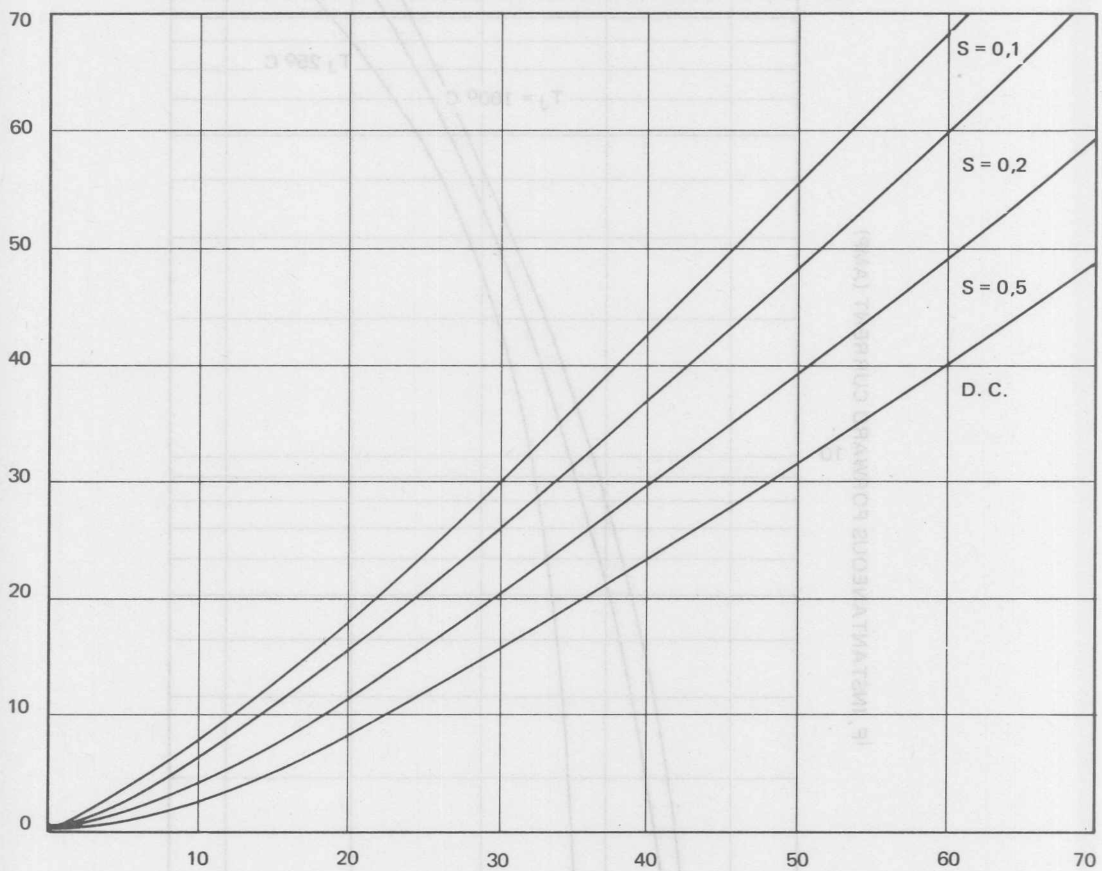


FIGURE 3 – FORWARD POWER DISSIPATION



$P_{F(AV)}$, AVERAGE FORWARD POWER DISSIPATION (WATTS)

$I_{F(AV)}$, AVERAGE FORWARD CURRENT (AMP)

MOTOROLA

BYS 75 SERIES

ADVANCE INFORMATION

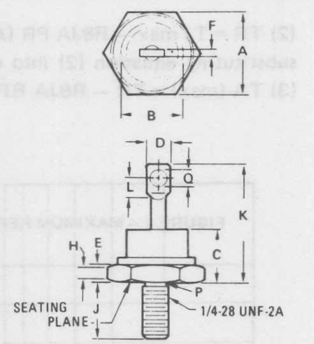
SCHOTTKY BARRIER RECTIFIERS

75 AMPERES
20 to 50 VOLTS

Switchmode Power Rectifiers

Epitaxial construction with oxyde passivation and metal overlap contact — ion implanted guard ring for transient voltage protection

- lowest combinated power losses
- high surge capability
- majority carrier conduction



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.96	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

MAXIMUM RATINGS

Rating	Symbol	BYS75 –20	BYS75 –30	BYS75 –45	BYS75 –50	Units
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	45	50	Volts
Average Rectified Forward Current, Rated V_R Square Wave	$I_{F\ (AV)}$	75 (T_C = 100° C)		75 (T_C = 90° C)		Amp.
Non-Repetitive Peak Surge Current, 10 mS	I_{FSM}	← 1000 →				Amp.
Operating and Storage Junction Temperature	T_J, T_{STG}	← –65 to +150 →				°C
Peak Operating Junction Temperature	$T_{J\ (PK)}$	← 175 →				°C
Voltage Rate of Change	dv/dT	← 1000 →				Volts µ Sec.

THERMAL CHARACTERISTICS

Characteristics	Symbol	Typ	Max.	Unit
Thermal Resistance Jonction to case	$R_{\theta jc}$	0.6	0.75	° C/W

ELECTRICAL CHARACTERISTICS

Characteristics		Symbol	Typ	Max.	Units
Instantaneous Forward Voltage					
I_F = 75 Amp.	T_C = 25° C	V_F	0.6	0.72	Volts
	T_C = 100° C		0.55	0.64	
	T_C = 150° C		0.53	–	
I_F = 150 Amp.	T_C = 25° C		0.8	0.88	
	T_C = 100° C		0.68	0.78	
	T_C = 150° C		0.64	–	
Instantaneous Reverse Current, Rated V_R					
T_C = 25° C	BYS75–20/30	I_R	90	1000	µA
	BYS75–45/50		130	1200	
T_C = 100° C	BYS75–20/30		15	25	mA
	BYS75–45/50		40	50	
Minimum Reverse Breakdown Voltage (I_{BR} = 10 mA, T_C = 25° C)		V_{BR}	30 40	47 53	Volts

MECHANICAL CHARACTERISTICS

CASE: welded, hermetically sealed
POLATITY: cathode to case
MOUNTING POSITIONS: any
STUD TORQUE: 25 in. lb. max.

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be covered when operating this rectifier at reverse voltages above 0,2 VRWM. Proper operating may be accomplished by use of equation:

(1) TA (max) = TJ max − RθJA.PF (AV) − RθJA PR (AV)

where:

TA (max) = maximum allowable ambient temperature
TJ (max) = maximum allowable junction temperature
PF (AV) = average forward power dissipation
PR (AV) = average reverse power dissipation
RθJA = junction to ambient thermal resistance

Figure 1 permits easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figure solves for a reference temperature as determined by equation (2):

(2) TR = TJ max − RθJA PR (AV)

substituting equation (2) into equation (1) yields:

(3) TA (max) = TR − RθJA RF (AV)

HOW TO USE FIG. 1 TO FIND TR (MAX)

Example:
Find TA (max) for BYS 60−30 operated in a 5 V/60 A forward converter as frectifiyng diode, 5 min = 0,35, 5 max = 0,5, VRRM = 17 V and R0JA = 3° C/W

STEP 1

Find VR equivalent = VRRM $\sqrt{1-5}$ min = 17 $\sqrt{0,65}$ = 13,7 V

STEP 2

Find TR from fig. 1 horizontaly intercept VR = 13,7V with the BYS 75−30 curve. Vertically intercept this point with the RθJA = 3° C/W curve. Read directly, TRT= 140° C.

STEP 3

Find PF (AV) from fig. 4 (IF (AV) for the rectifying diode is Io x 5 max IF (AV) = Io.0,5 = 30A) Read PF (AV) = 18 W

STEP 4

Find TA (max) from equation (3)
TA max = TR − RθJA. PF (AV)
= 140° C−86° C

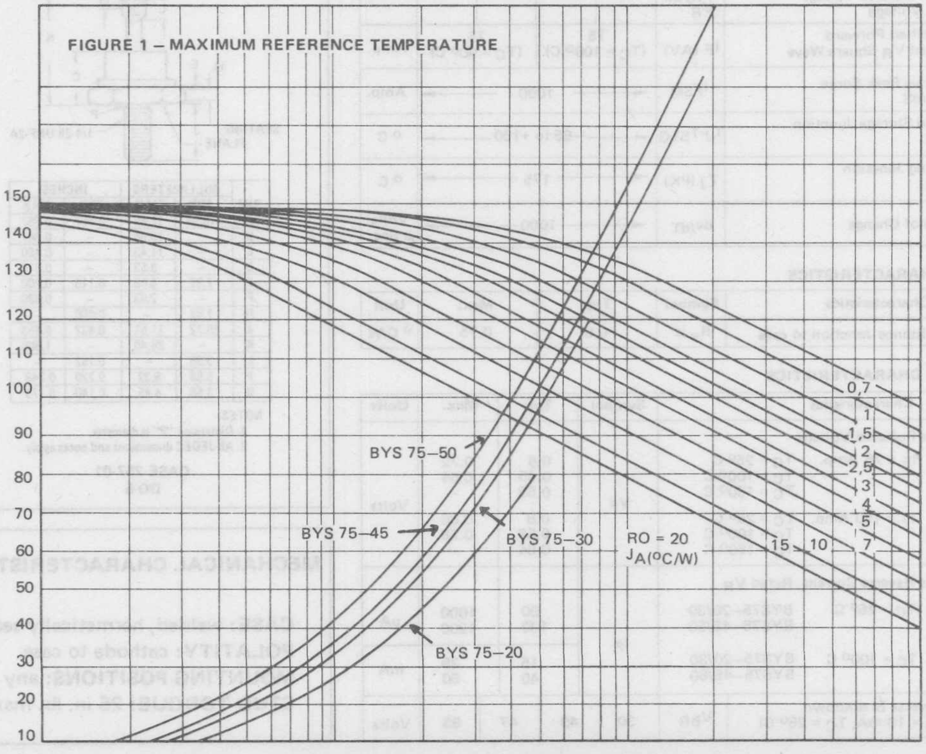


FIGURE 2 – TYPICAL FORWARD VOLTAGE

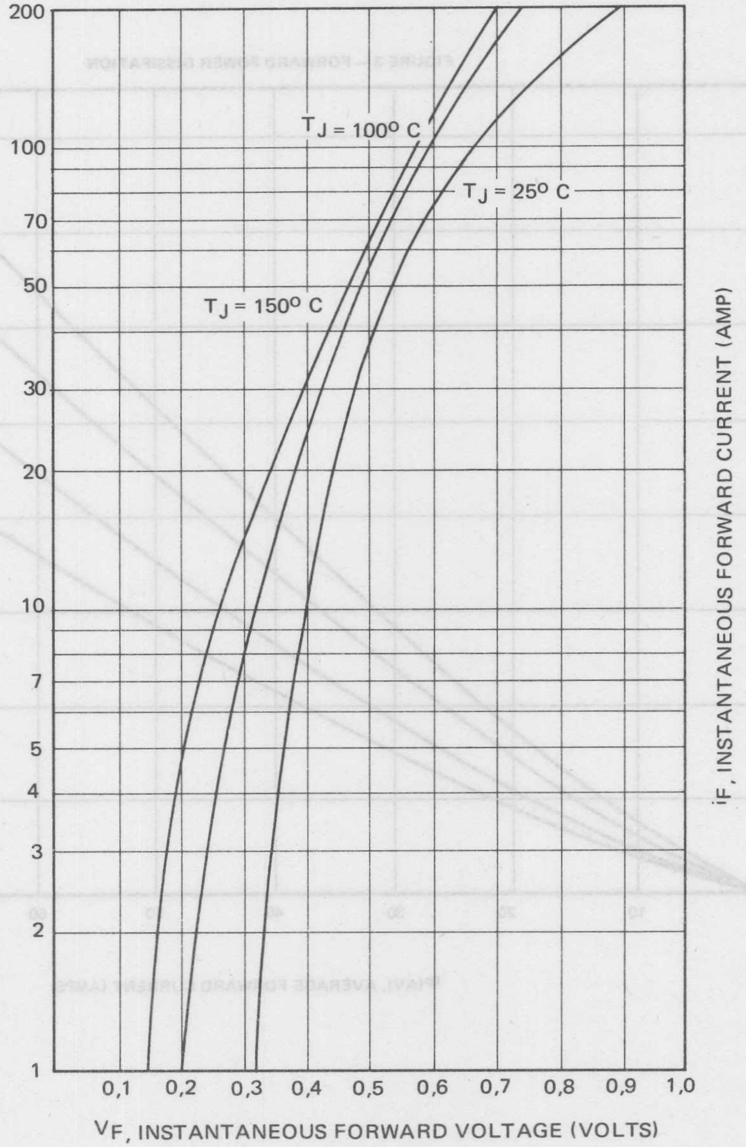
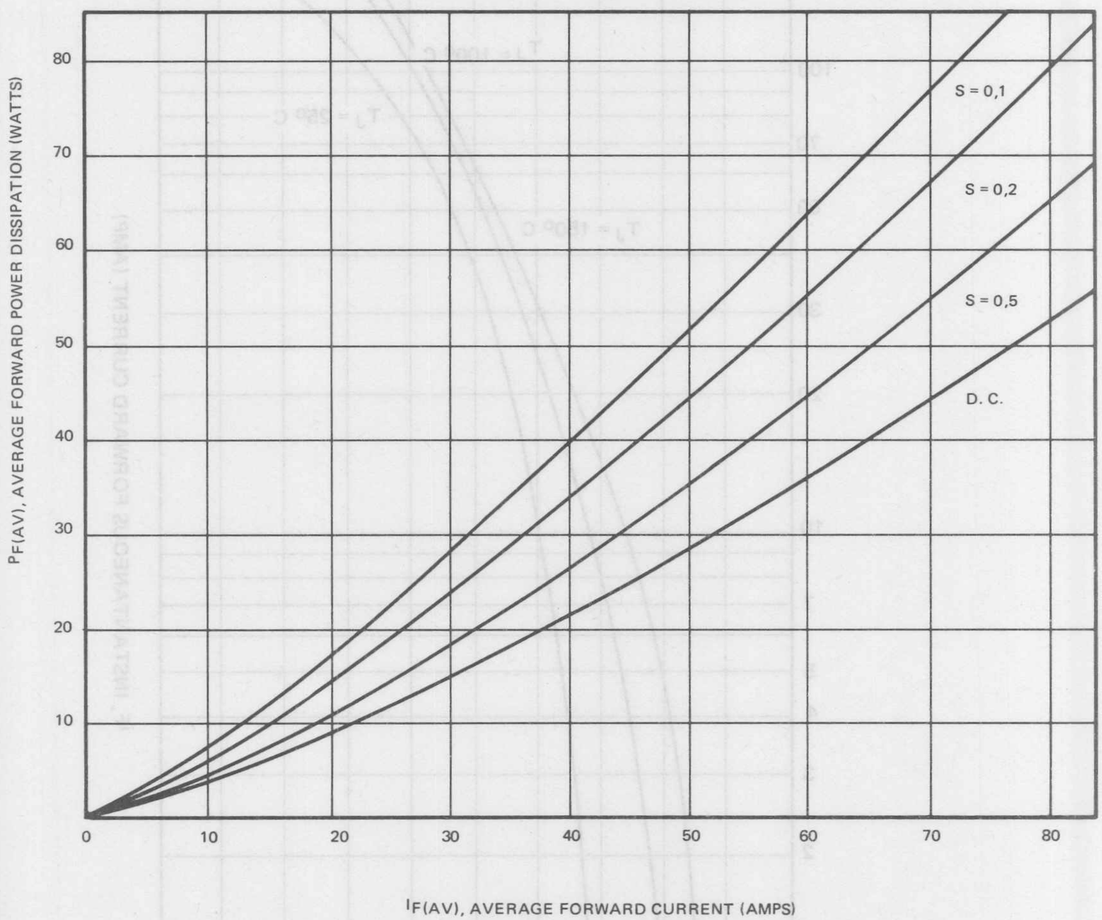
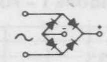


FIGURE 3 – FORWARD POWER DISSIPATION



MOTOROLA

BYT 25—50 thru BYT 25—1000 SERIES



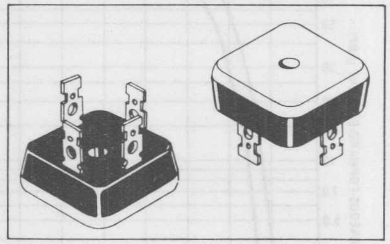
MINIATURE SINGLE PHASE FULL-WAVE BRIDGE

25 AMPERES
50–1000 VOLTS

RECTIFIER ASSEMBLY

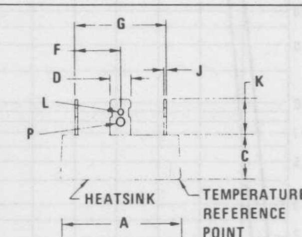
. . . utilizing individual void-free molded rectifiers, interconnected and mounted on an electrically isolated aluminum heat sink by a high thermal-conductive epoxy resin.

- 400 Ampere Surge Capability
- Electrically Isolated Base
- 1800 Volt Heat Sink Isolation
- **Maximum space saving**



MAXIMUM RATINGS

Rating (Per Diode)	Symbol	BYT25 50	100	200	400	600	800	1000	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
DC Output Voltage Resistive Load Capacitive Load	Vdc	 30 50	 62 100	 124 200	 250 400	 380 600	 500 800	 630 1000	Volts
Sine Wave RMS Input Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (Single phase bridge, resistive load, 50 Hz, T_C = 55 °C	I_O	25							Amp
Non-Repetitive Peak Surge Current applied (Surge at rated load conditions)	I_{FSM}	400							Amp
Operating and Storage Junction	T_J, T_{stg}	−60 to +175							°C

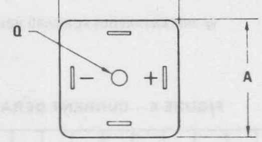


THERMAL CHARACTERISTICS

Characteristic	Symbol	Typ	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$			°C/W
Each Die		8.0	10	
Total Bridge		2.0	2.8	

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) (i_F = 40 A)	V_F	–	0.95	1.05	Volts
Reverse Current (Per Diode) (Rated V_R)	I_R	–	–	0.10	mA



NOTE:
1. DIM "Q" SHALL BE MEASURED ON HEATSINK SIDE OF PKG.

DIM	MILLIMETERS MIN	MAX	INCHES MIN	MAX
A	25.65	26.16	1.010	1.030
C	12.44	13.97	0.490	0.550
D	6.10	6.60	0.240	0.260
F	10.01	10.49	0.394	0.413
G	19.99	21.01	0.787	0.827
J	0.71	0.86	0.028	0.034
K	10.41	11.43	0.410	0.450
L	1.52	2.06	0.060	0.081
P	2.79	2.92	0.110	0.115
Q	4.42	4.67	0.174	0.184

CASE 309A-03

MECHANICAL CHARACTERISTICS

CASE: Plastic case with an electrically isolated aluminum base.

POLARITY: Terminal designation embossed on case:
+DC output
−DC output
AC not marked

MOUNTING POSITION: Bolt down. Highest heat transfer efficiency accomplished through the surface opposite the terminals. Use silicone heat sink compound on mounting surface for maximum heat transfer.

WEIGHT: 25 grams (approx.)

TERMINALS: Suitable for fast-on connections. Readily solderable, corrosion resistant. Soldering recommended for applications greater than 15 amperes.

MOUNTING TORQUE: 20 in. lb. max.

FIGURE 1 – FORWARD VOLTAGE

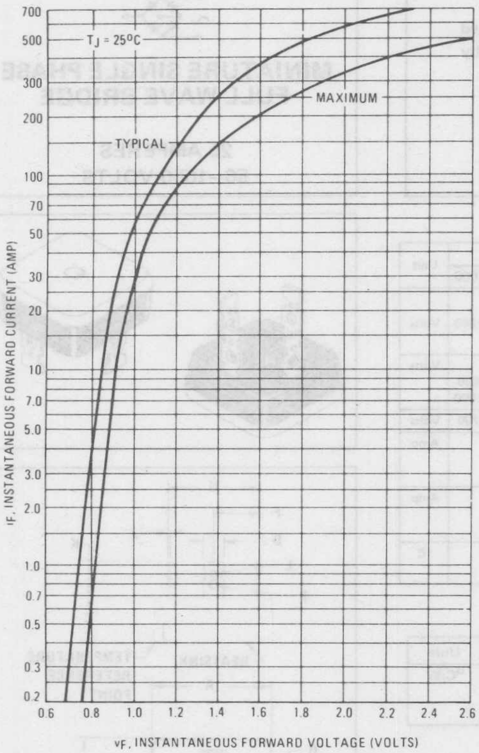


FIGURE 2 – NON REPETITIVE SURGE CURRENT

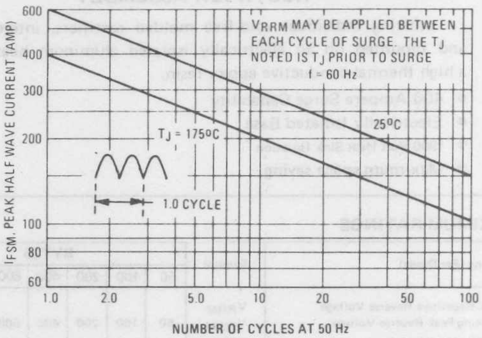


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

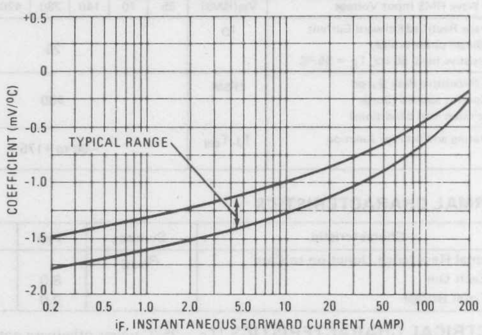


FIGURE 4 – CURRENT DERATING

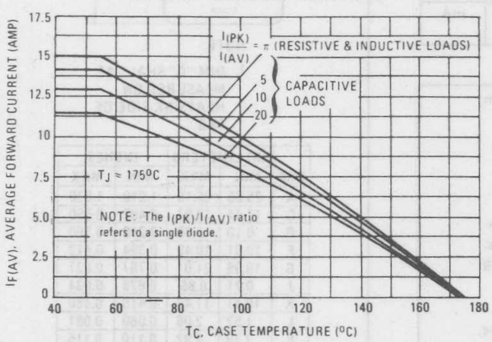


FIGURE 5 – FORWARD POWER DISSIPATION

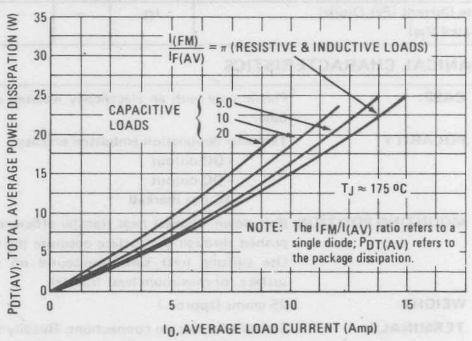
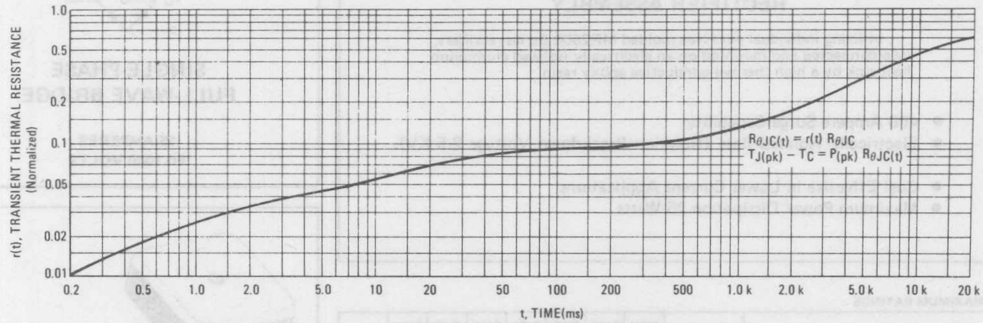
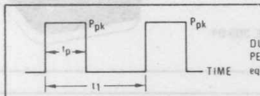


FIGURE 6 – TYPICAL THERMAL RESPONSE



NOTE 1



DUTY CYCLE, $D = t_p / t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 8, i.e.,
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

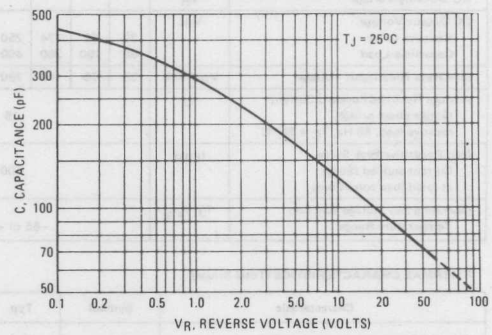


FIGURE 8 – FORWARD RECOVERY TIME

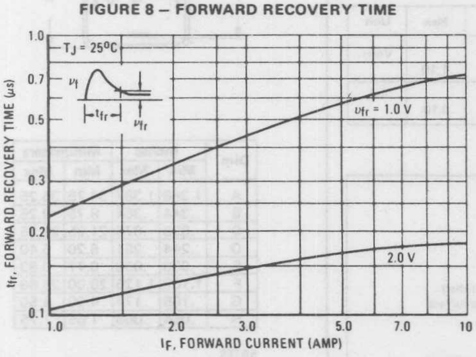
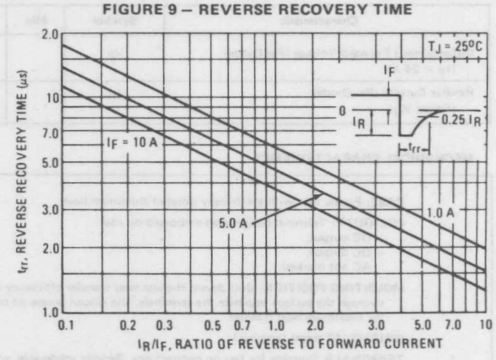
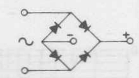


FIGURE 9 – REVERSE RECOVERY TIME



MOTOROLA

BYW 20 SERIES



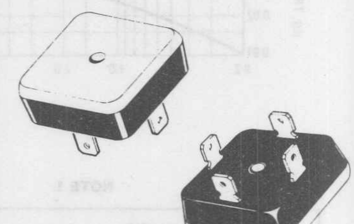
SINGLE-PHASE FULL-WAVE BRIDGE

15 AMPERES
50-1000 VOLTS

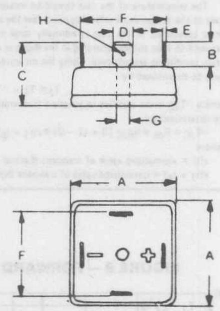
RECTIFIER ASSEMBLY

. . . utilizing individual void-free molded MR2500 Series rectifiers, interconnected and mounted on an electrically isolated aluminium heat sink by a high thermal-conductive epoxy resin.

- 400 Ampere Surge Capability
- Electrically Isolated Base (Isolation Breakdown Voltage 2.5 KV).
- Cost Effective in Lower Current Applications
- Maximum Power Dissipation 25 Watts



CASE 309-01



Dim	Inches		Millimeters	
	Min	Max	Min	Max
A	1.368	1.387	34.75	35.25
B	.344	.364	8.75	9.25
C	.836	.875	21.25	22.25
D	.244	.251	6.20	6.40
E	.030	.032	0.77	0.83
F	1.102	1.125	28.00	28.60
G	.165	.177	4.20	4.50
H	.064	.068	1.65	1.75

NOTES
1. Hole is counter sunk for # 6 socket head screw.
2. Dim. "B", "C", "D", "E" and "H" are typical.

MAXIMUM RATINGS

Rating (Per Diode)	Symbol	BYW 20	BYW 21	BYW 22	BYW 24	BYW 26	BYW 28	BYW 79	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
DC Output Voltage Resistive Load Capacitive Load	Vdc	30 50	62 100	124 200	250 400	380 600	500 800	630 1000	Volts
Sine Wave RMS Input Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (Single phase bridge, resistive load, 50 Hz, $T_C = 55\ °C$	I_O	15							Amp
Non-Repetitive Peak Surge Current applied (Surge at rated load conditions)	I_{FSM}	400							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +175							°C

THERMAL CHARACTERISTICS (Total Bridge)

Characteristic	Symbol	Typ	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	2.1	2.75	°C/W

ELECTRICAL CHARACTERISTICS ($T_C = 25\ °C$ unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) ($I_F = 24$ A)	V_F	–	1,0	1,10	Volts
Reverse Current (Per Diode) (Rated V_R)	I_R	–	–	0.10	mA

MECHANICAL CHARACTERISTICS

CASE: Plastic case with electrically isolated aluminum base.

POLARITY: Terminal designation embossed on case:
+ DC output,
− DC output,
AC not marked.

MOUNTING POSITION: Bolt down. Highest heat transfer efficiency accomplished through the surface opposite the terminals. Use silicon grease on mounting surface for maximum heat transfer.

WEIGHT: 40 grams (approx.)

TERMINALS: Suitable for fast-on connections. Readily solderable, corrosion resistant. Soldering recommended for applications greater than 15 Amperes.

MOUNTING TORQUE: 0,23 Kg.-m. Max.

E-001 –

FIGURE 1 – FORWARD VOLTAGE

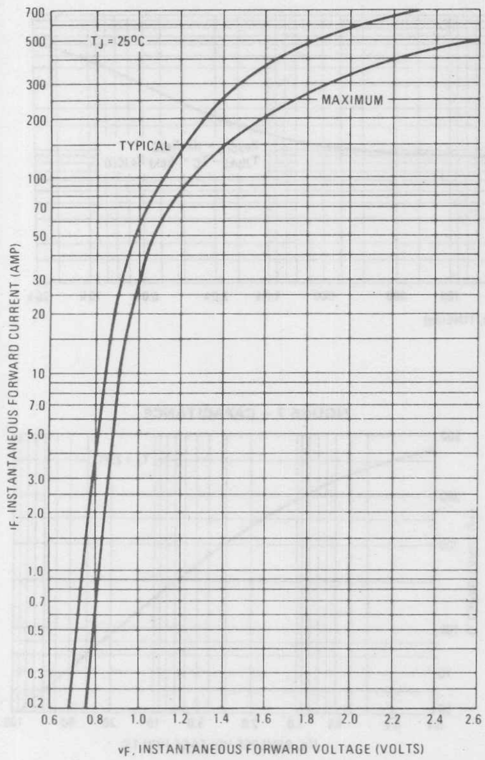


FIGURE 2 – NON REPETITIVE SURGE CURRENT

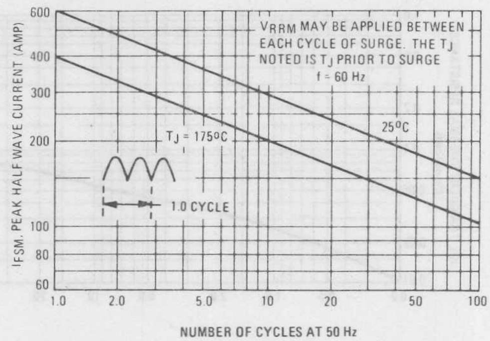


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

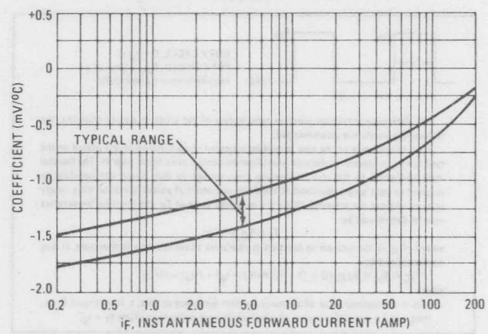


FIGURE 4 – CURRENT DERATING

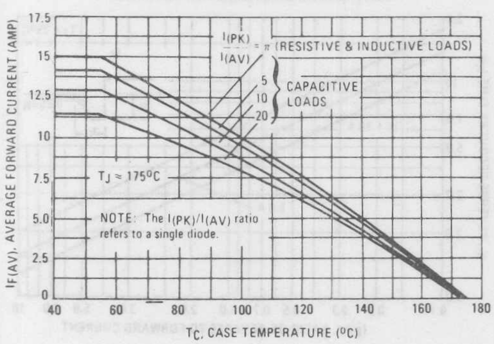


FIGURE 5 – FORWARD POWER DISSIPATION

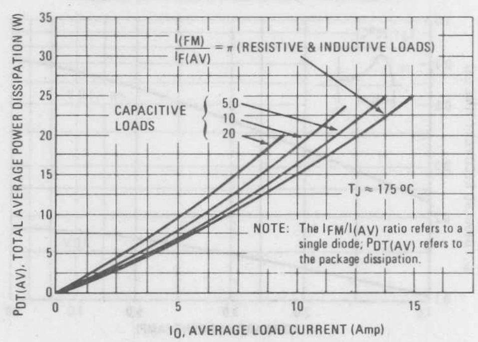
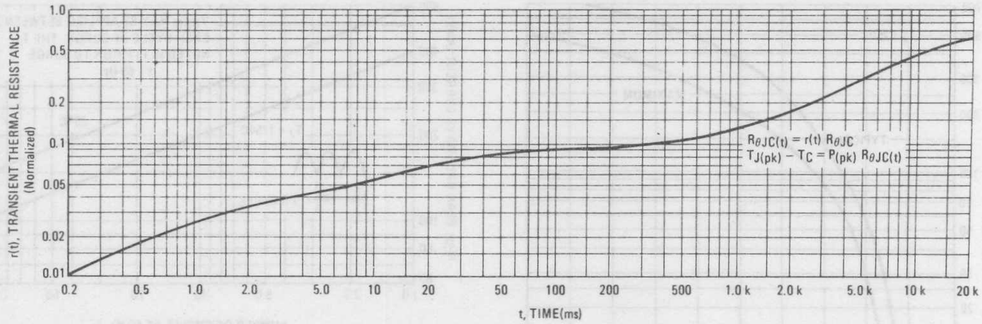
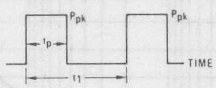


FIGURE 6 – TYPICAL THERMAL RESPONSE



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 8, i.e.,
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

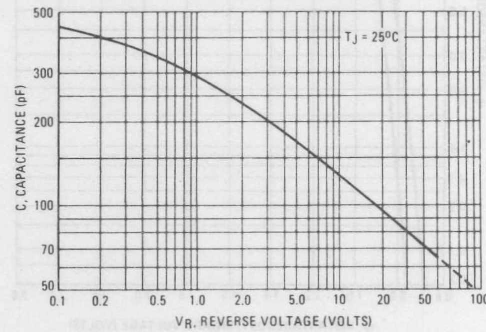


FIGURE 8 – FORWARD RECOVERY TIME

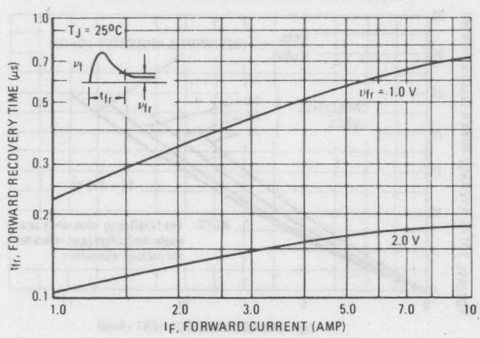
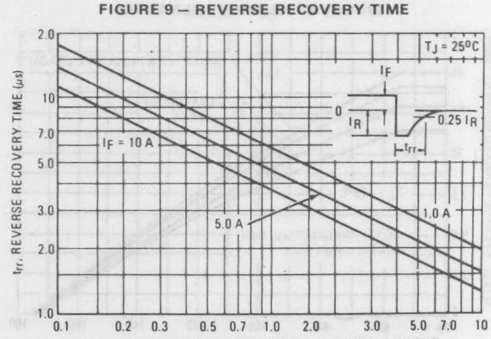


FIGURE 9 – REVERSE RECOVERY TIME



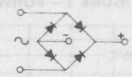
MOTOROLA

BYW 60 SERIES

RECTIFIER ASSEMBLY

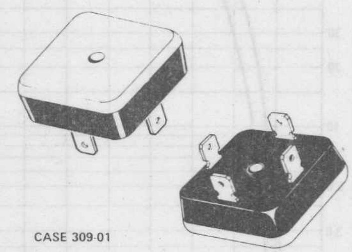
. . . utilizing individual void-free molded MR2500 Series rectifiers, interconnected and mounted on an electrically isolated aluminium heat sink by a high thermal-conductive epoxy resin.

- 400 Ampere Surge Capability
- Electrically Isolated Base (Isolation Breakdown Voltage 2.5 KV).
- Fast Recovery Available on Request
- Cost Effective in Lower Current Applications
- Maximum Power Dissipation 67 Watts



SINGLE-PHASE FULL-WAVE BRIDGE

35 AMPERES
50-1000 VOLTS



CASE 309-01

MAXIMUM RATINGS

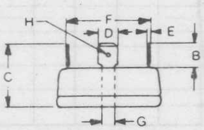
Rating (Per Diode)	Symbol	BYW 60	BYW 61	BYW 62	BYW 64	BYW 66	BYW 68	BYW 89	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
DC Output Voltage Resistive Load Capacitive Load	Vdc	30 50	62 100	124 200	250 400	380 600	500 800	630 1000	Volts
Sine Wave RMS Input Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (Single phase bridge, resistive load, 50 Hz, T_C = 55 °C	I_O	35							Amp
Non-Repetitive Peak Surge Current applied (Surge at rated load conditions)	I_{FSM}	400							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +175							°C

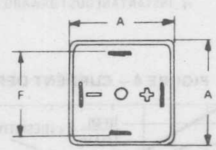
THERMAL CHARACTERISTICS (Total Bridge)

Characteristic	Symbol	Typ	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.4	1.87	° C/W

ELECTRICAL CHARACTERISTICS (T_C = 25 °C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) (I_F = 55 A)	V_F	–	1.0	1.1	Volts
Reverse Current (Per Diode) (Rated V_R)	I_R	–	–	0.10	mA





Dim	Inches Min	Inches Max	Millimeters Min	Millimeters Max
A	1.368	1.387	34.75	35.25
B	.344	.364	8.75	9.25
C	.836	.875	21.25	22.25
D	.244	.251	6.20	6.40
E	.030	.032	0.77	0.83
F	1.102	1.125	28.00	28.60
G	.165	.177	4.20	4.50
H	.064	.068	1.65	1.75

NOTES
1. Hole is counter sunk for # 6 socket head screw.
2. Dim. "B", "C", "D", "E" and "H" are typical.

MECHANICAL CHARACTERISTICS

CASE: Plastic case with electrically isolated aluminum base.

POLARITY: Terminal designation embossed on case:
+ DC output,
– DC output,
AC not marked.

MOUNTING POSITION: Bolt down. Highest heat transfer efficiency accomplished through the surface opposite the terminals. Use silicon grease on mounting surface for maximum heat transfer.

WEIGHT: 40 grams (approx.)

TERMINALS: Suitable for fast-on connections. Readily solderable, corrosion resistant. Soldering recommended for applications greater than 15 Amperes.

MOUNTING TORQUE: 0,23 Kg.-m. Max.

FIGURE 1 – FORWARD VOLTAGE

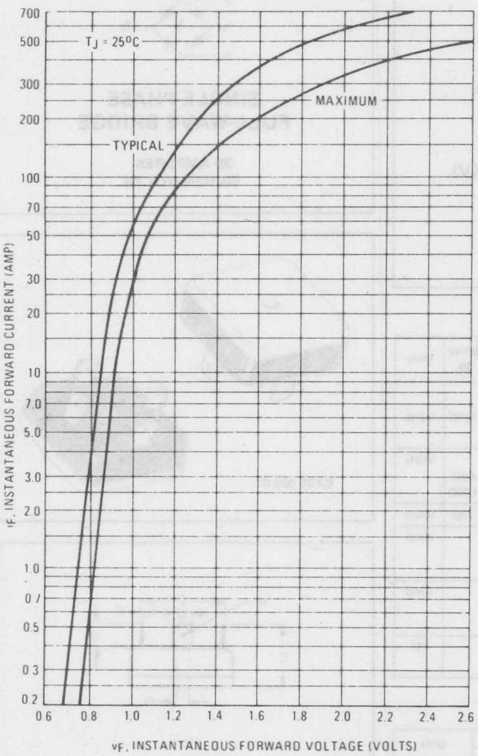


FIGURE 2 – NON REPETITIVE SURGE CURRENT

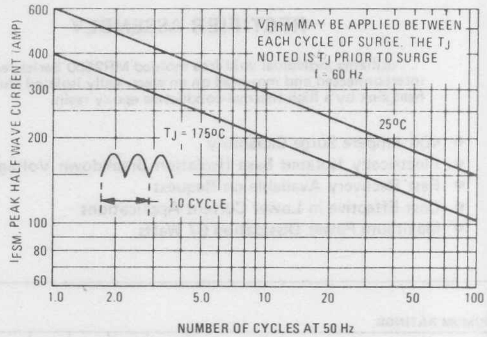


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

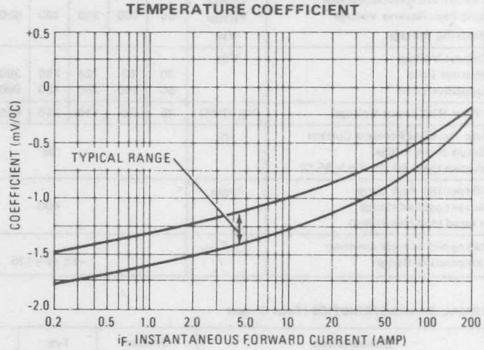


FIGURE 4 – CURRENT DERATING

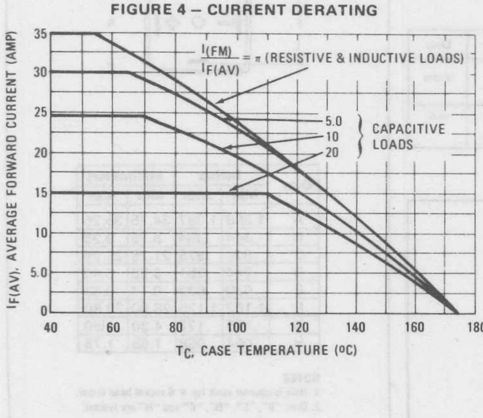


FIGURE 5 – FORWARD POWER DISSIPATION

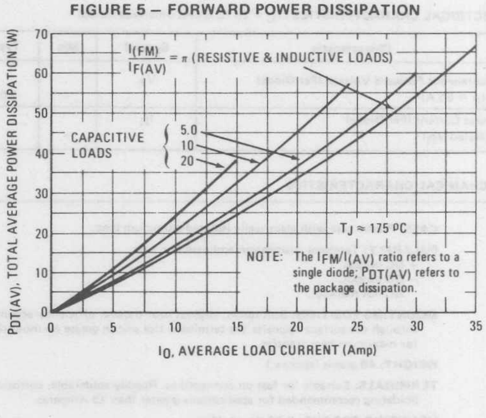
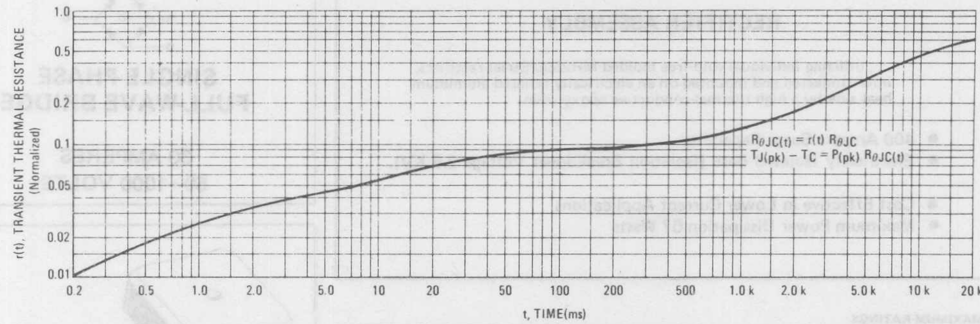
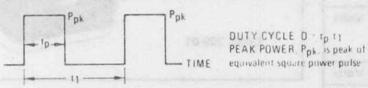


FIGURE 6 – TYPICAL THERMAL RESPONSE



NOTE 1



DUTY CYCLE $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse

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$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC}\,[D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 8, i.e.,
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

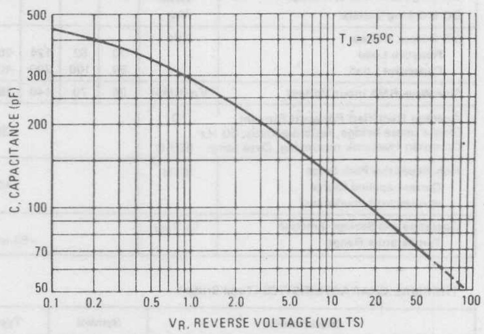


FIGURE 8 – FORWARD RECOVERY TIME

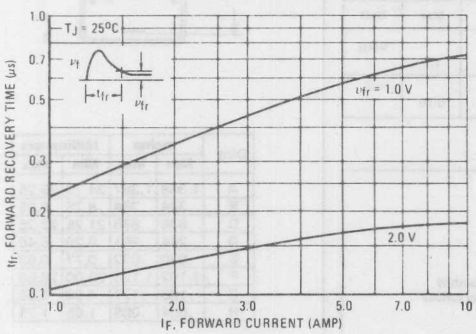
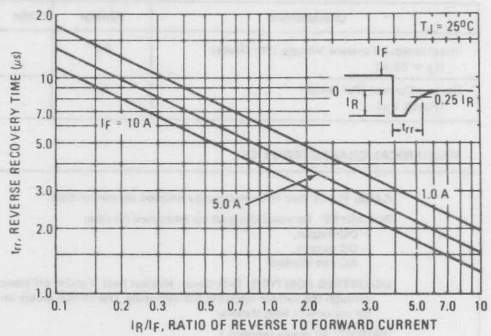


FIGURE 9 – REVERSE RECOVERY TIME



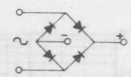
MOTOROLA

BYW 60 M SERIES

RECTIFIER ASSEMBLY

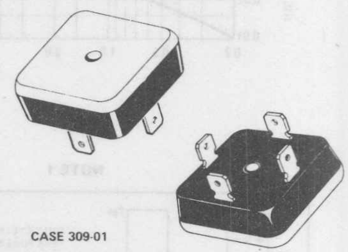
. . . utilizing individual void-free molded MR2500 Series rectifiers, interconnected and mounted on an electrically isolated aluminium heat sink by a high thermal-conductive epoxy resin.

- 400 Ampere Surge Capability
- Electrically Isolated Base (Isolation Breakdown Voltage 2.5 KV).
- Cost Effective in Lower Current Applications
- Maximum Power Dissipation 67 Watts



SINGLE-PHASE FULL-WAVE BRIDGE

30 AMPERES
50–1000 VOLTS



CASE 309-01

MAXIMUM RATINGS

Rating (Per Diode)	Symbol	BYW 60M	BYW 61 M	BYW 62 M	BYW 64 M	BYW 66 M	BYW 68 M	BYW 89 M	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
DC Output Voltage Resistive Load Capacitive Load	Vdc	 30 50	 62 100	 124 200	 250 400	 380 600	 500 800	 630 1000	Volts
Sine Wave RMS Input Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current Single phase bridge, resistive loads, 50 Hz Comman Heatsink mounting, Case temp.: 50° C	I_O				30				Amp
Non-Repetitive Peak Surge Current applied (Surge at rated load conditions)	I_{FSM}				400				Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}				−65 to +175				°C

THERMAL CHARACTERISTICS (Total Bridge)

Characteristic	Symbol	Typ	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.4	1.87	° C/W

ELECTRICAL CHARACTERISTICS (T_C = 25 °C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) (I_F = 55 A)	V_F	–	1.0	1.1	Volts
Reverse Current (Per Diode) (Rated V_R)	I_R	–	–	0.10	mA

MECHANICAL CHARACTERISTICS

CASE: Plastic case with electrically isolated aluminum base.

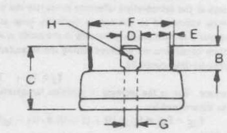
POLARITY: Terminal designation embossed on case:
+ DC output,
– DC output,
AC not marked.

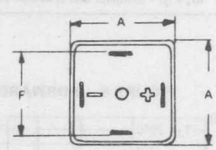
MOUNTING POSITION: Bolt down. Highest heat transfer efficiency accomplished through the surface opposite the terminals. Use silicon grease on mounting surface for maximum heat transfer.

WEIGHT: 40 grams (approx.)

TERMINALS: Suitable for fast-on connections. Readily solderable, corrosion resistant. Soldering recommended for applications greater than 15 Amperes.

MOUNTING TORQUE: 0,23 Kg.-m. Max.





Dim	Inches Min	Inches Max	Millimeters Min	Millimeters Max
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B	.344	.364	8.75	9.25
C	.836	.875	21.25	22.25
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NOTES
1. Hole is counter sunk for # 6 socket head screw.
2. Dim. "B", "C", "D", "E" and "H" are typical.

FIGURE 1 – FORWARD VOLTAGE

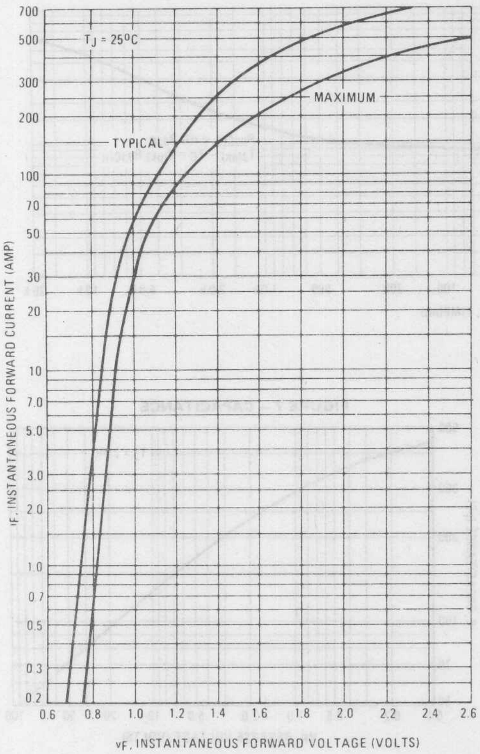


FIGURE 2 – NON REPETITIVE SURGE CURRENT

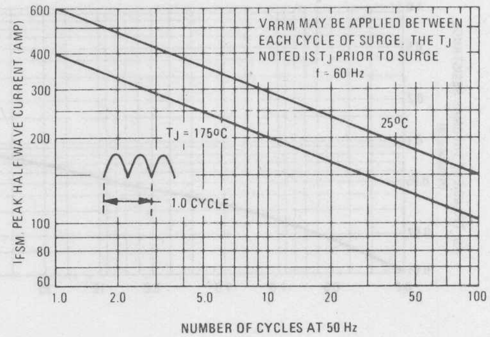


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

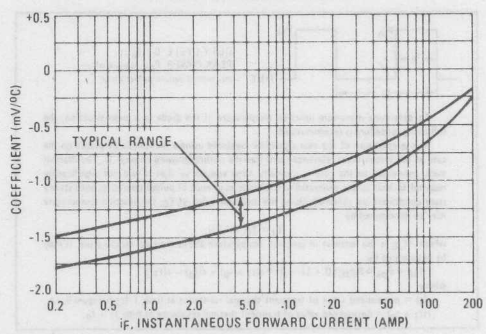


FIGURE 4 – CURRENT DERATING

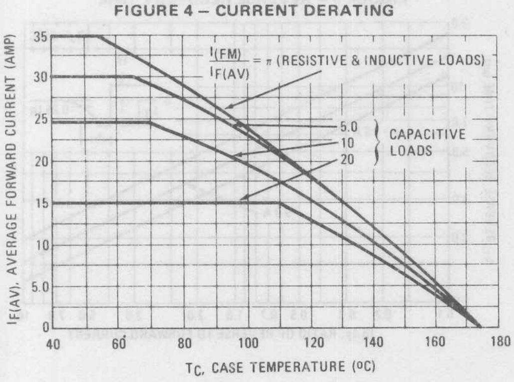


FIGURE 5 – FORWARD POWER DISSIPATION

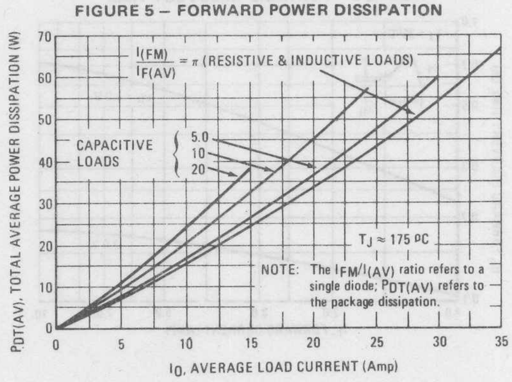
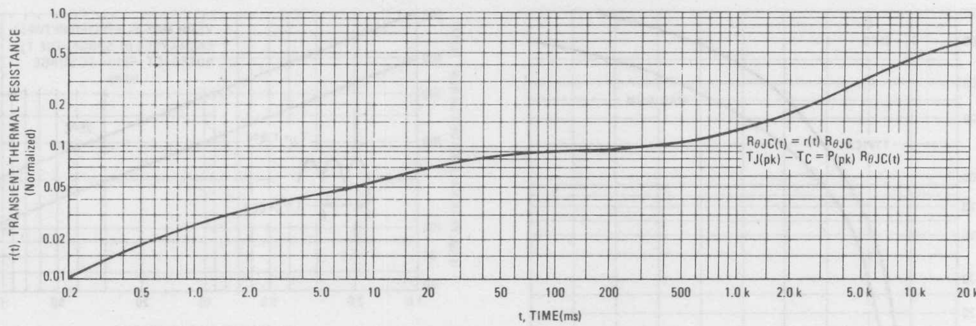
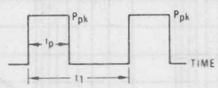


FIGURE 6 – TYPICAL THERMAL RESPONSE



NOTE 1



DUTY CYCLE $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC}\,[D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 8, i.e.,
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

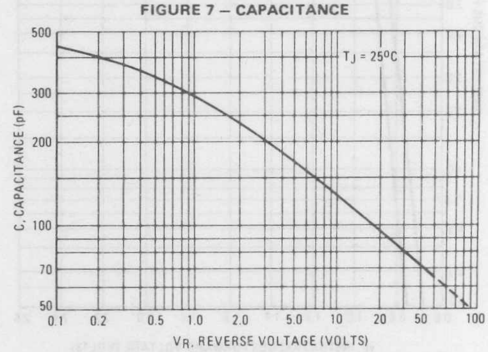


FIGURE 8 – FORWARD RECOVERY TIME

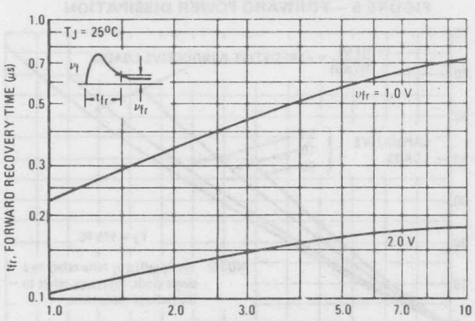
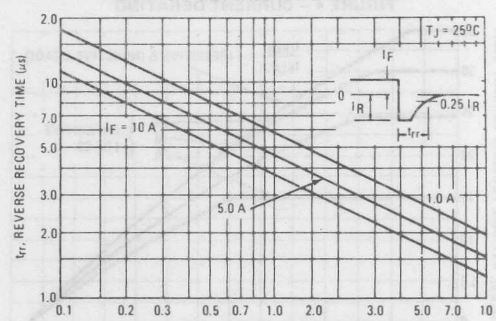


FIGURE 9 – REVERSE RECOVERY TIME



MOTOROLA

BYX 10

Designers Data Sheet

"SURMETIC" RECTIFIERS

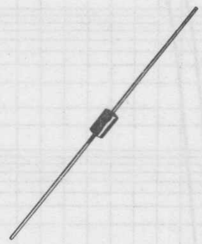
. . . subminiature size, axial lead-mounted rectifier for general-purpose, low-power applications.

Designers Data for "Worst Case" Conditions

The Designers Data Sheets permit the design of most circuits entirely from the information presented. Limits curves—representing boundaries on device characteristics—are given to facilitate "worst-case" design.

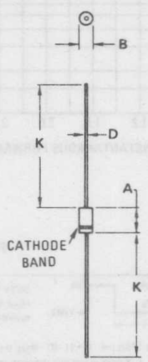
LEAD-MOUNTED SILICON RECTIFIER

1600 VOLTS
0,5 AMPERE



MAXIMUM RATINGS

Rating	Symbol	B Y X 10	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	800*	Volts
Nonrepetitive Peak Reverse Voltage (Halfwave, Single Phase, 60 Hz)	V_{RSM}	1600*	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	560*	Volts
Average Rectified Forward Current (Single Phase, Resistive Load, 60 Hz, T_L = 70°C, 1/2" From Body)	I_O	0.5* 1.0* (MOTOROLA SPECIFIED)	Amp
Nonrepetitive Peak Surge Current (Surge Applied at Rated Load Conditions, See Figure 2)	I_{FSM}	30 (for 1 cycle)	Amp
Storage Temperature Range	T_{stg}	-65 to +175	°C
Operating Temperature Range	T_L	-65 to +170	°C
DC Blocking Voltage Temperature	T_L	150	°C



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

CASE 59-04

Dimensions Within JEDEC DO-15 Outline.

ELECTRICAL CHARACTERISTICS

Characteristic and Conditions	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage Drop (i_F = 2.0 Amp Peak, T_L = 170° C, 1/2 Inch Leads)	v_F	–	1.1	Volts
Maximum Reverse Current (Rated dc Voltage) T = 25° C	I_R		1.0	µA
T_J = 125° C			50	µA

* Indicates Pro-electron Registered Data

MECHANICAL CHARACTERISTICS

CASE: Void free, transfer molded

MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 240°C, 1/8" from case for 10 seconds at 5 lbs. tension

FINISH: All external surfaces are corrosion-resistant, leads are readily solderable

POLARITY: Cathode indicated by color band

WEIGHT: 0.40 grams (approximately)

FIGURE 1 – FORWARD VOLTAGE

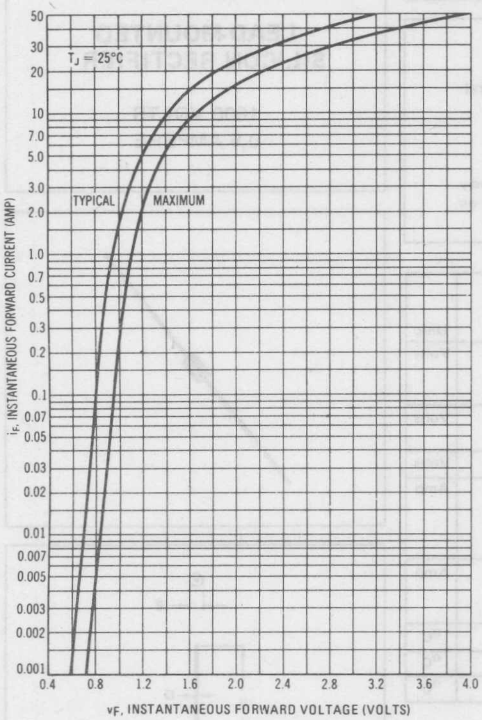


FIGURE 2 – MAXIMUM NONREPETITIVE SURGE CURRENT

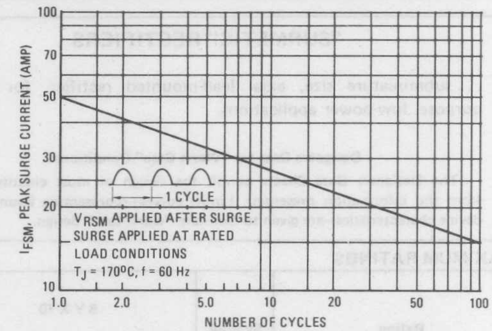


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

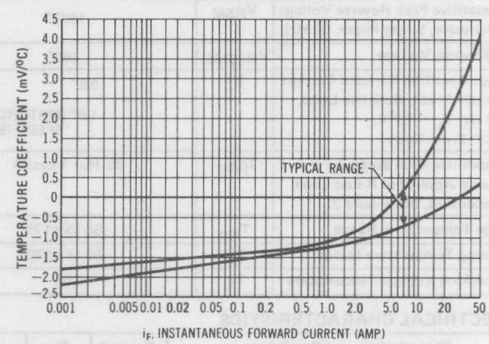
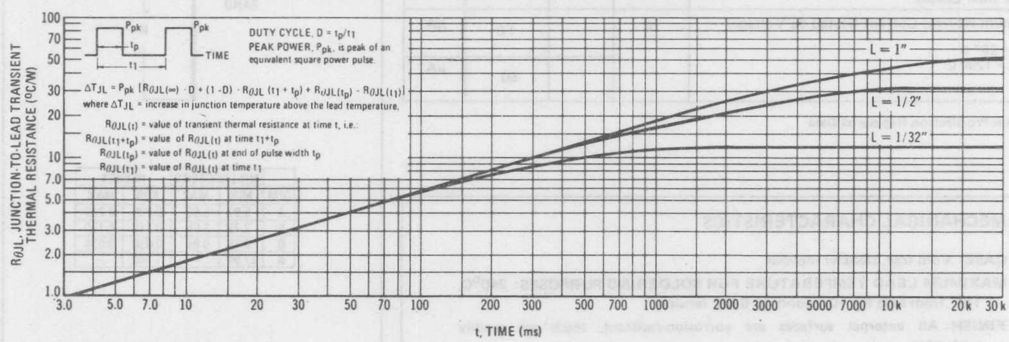


FIGURE 4 – TYPICAL TRANSIENT THERMAL RESISTANCE



The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

$$T_J = T_L + \Delta T_{JL}.$$

FIGURE 5 – FORWARD POWER DISSIPATION

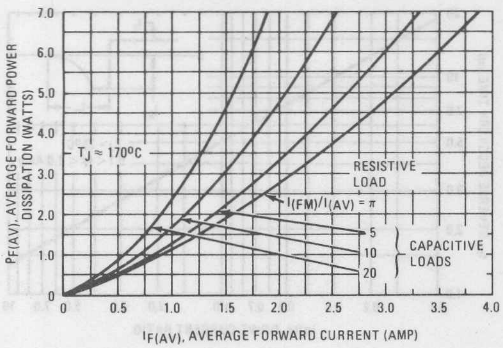


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

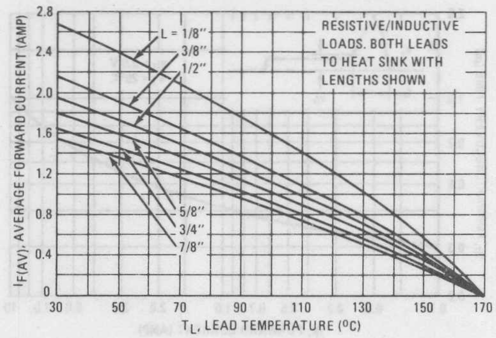


FIGURE 7 – 1/2″ LEAD LENGTH, VARIOUS LOADS

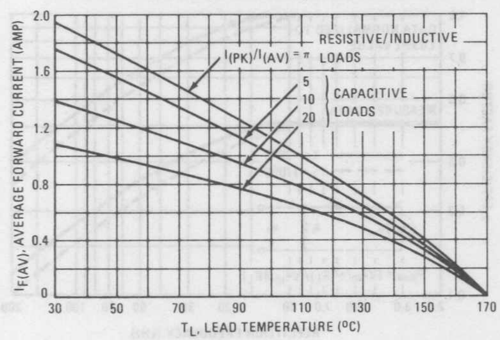


FIGURE 8 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

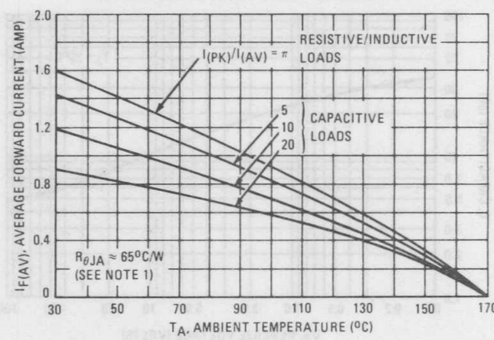
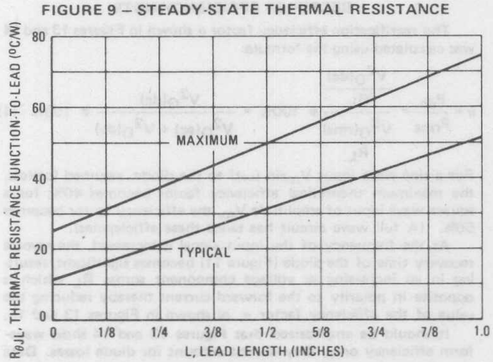


FIGURE 9 – STEADY-STATE THERMAL RESISTANCE



NOTE 1

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN)				
	1/8	1/4	1/2	3/4	$R_{\theta JA}$
1	65	72	82	92	$^oC/W$
2	74	81	91	101	$^oC/W$
3	40				$^oC/W$

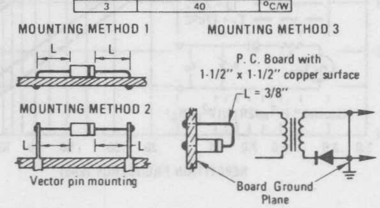


FIGURE 10 – FORWARD RECOVERY TIME

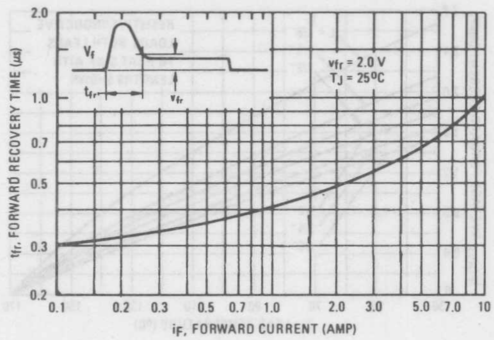


FIGURE 11 – REVERSE RECOVERY TIME

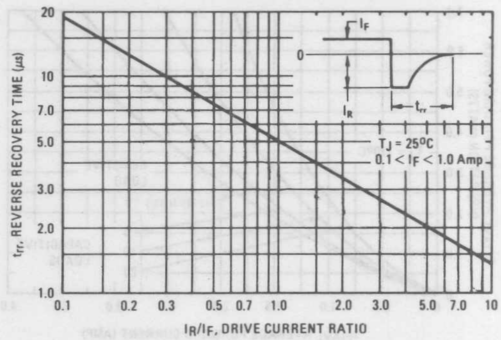


FIGURE 12 – JUNCTION CAPACITANCE

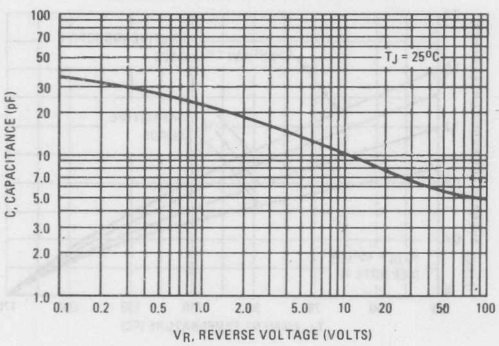


FIGURE 13 – RECTIFICATION WAVEFORM EFFICIENCY FOR SINE WAVE

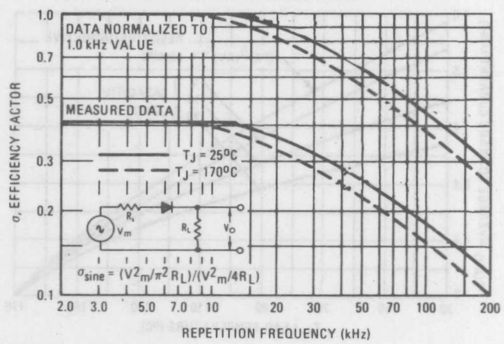
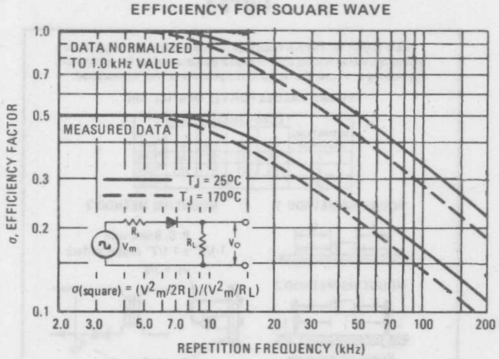


FIGURE 14 – RECTIFICATION WAVEFORM EFFICIENCY FOR SQUARE WAVE



RECTIFIER EFFICIENCY NOTE

The rectification efficiency factor σ shown in Figures 13 and 14 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\dfrac{V^2_{O(dc)}}{R_L}}{\dfrac{V^2_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2_{O(dc)}}{V^2_{O(ac)} + V^2_{O(dc)}} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assumed lossless, the maximum theoretical efficiency factor becomes 40%; for a square wave input of amplitude V_m, the efficiency factor becomes 50%. (A full wave circuit has twice these efficiencies).

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 11) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current thereby reducing the value of the efficiency factor σ, as shown in Figures 13 and 14.

It should be emphasized that Figures 13 and 14 show waveform efficiency only; they do not account for diode losses. Data was obtained by measuring the ac component of V_O with a true rms voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for the Figures.

MOTOROLA

BYX 55 SERIES

FAST SOFT RECOVERY POWER RECTIFIERS

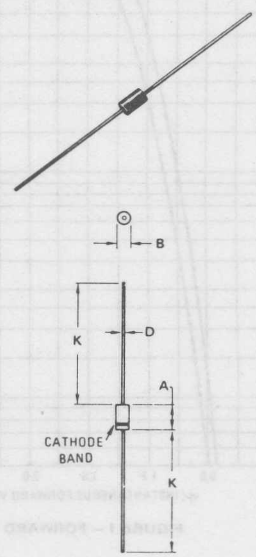
350 & 600 VOLTS
1.2 AMPERE

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 300 nanoseconds providing high efficiency at frequencies to 250 KHz.

DESIGNER'S DATA FOR "WORST CASE" CONDITIONS

The Designers▲ Data Sheet permits the design of most circuits entirely from the information presented. Limit curves — representing device characteristic boundaries — are given to facilitate "worst case" design.



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	-	1.100	-

CASE 59-04

MAXIMUM RATINGS

Ratings	Symbol	BYX 55-350	BYX 55-600	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	350	600	Volts
Non Repetitive Peak Reverse Voltage	V_{RSM}	350	600	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	240	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_A = 75\,°C$)	I_O	← 1.2 →		Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions) ($T_A = 75\,°C$)	I_{FSM}	← 40 →		Amps
Operating Junction Temperature Range	T_J	← −65 to +150 →		°C
Storage Temperature Range	T_{stg}	← −65 to +175 →		°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Typical Primted Circuit Board Mounting)	$R_{\theta JA}$	65	°C/W

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Forward Voltage ($I_F = 4.0$ AMP, $T_A = 25°C$)	V_F	–	1.0	1.25	Volts
Reverse Current (rated dc voltage) $T_A = 25°C$	I_R	–	1.0	10	µA
$T_A = 100°C$		–	50	100	

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time ($I_F = 1.0$ Amp to $V_R = 50$ Vdc) (Figure 21)	t_{rr}	–		350	ns
Reverse Recovery Current ($I_F = 1.0$ Amp to $V_R = 30$ Vdc) (Figure 21)	$I_{RM(REC)}$	–	–	3.0	Amp

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded

FINISH: External leads are tin plated, leads are readily solderable

POLARITY: Cathode indicated by Polarity band

WEIGHT: 0.4 Grams (Approximately)

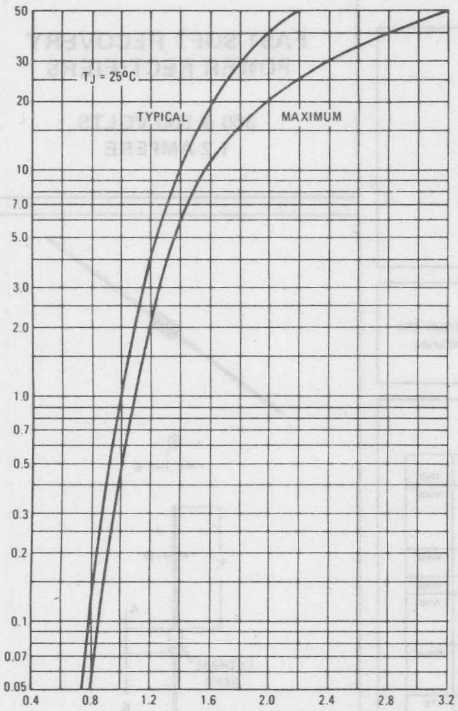


FIGURE 1 – FORWARD VOLTAGE

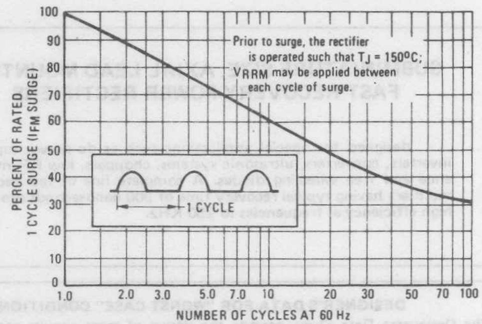


FIGURE 2 – MAXIMUM SURGE CAPABILITY

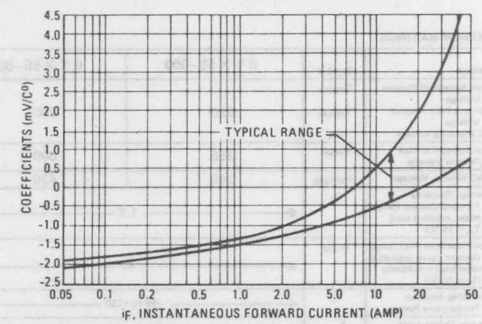


FIGURE 3 – TEMPERATURE COEFFICIENT

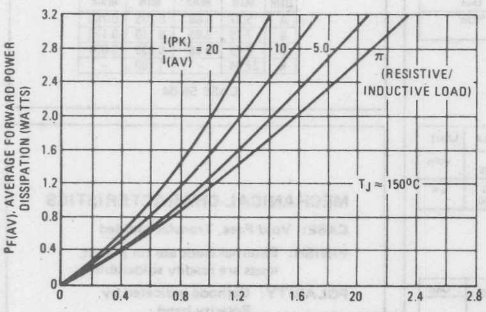


FIGURE 4 – FORWARD POWER DISSIPATION

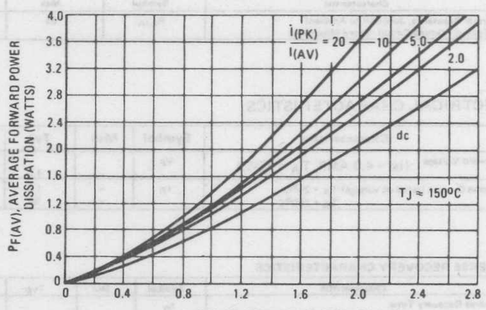


FIGURE 5 – FORWARD POWER DISSIPATION

MAXIMUM CURRENT RATINGS
(SEE NOTES 1 and 2)

SINE WAVE INPUT

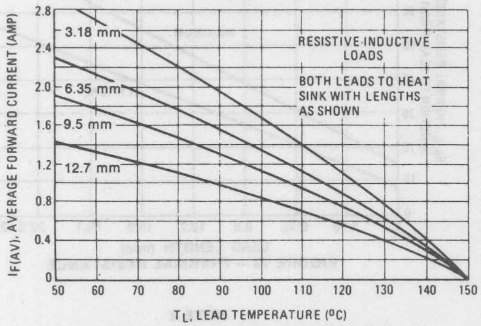


FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

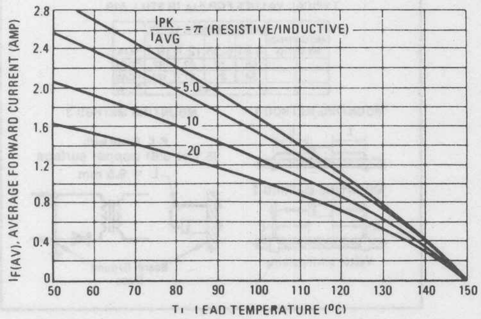


FIGURE 8 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

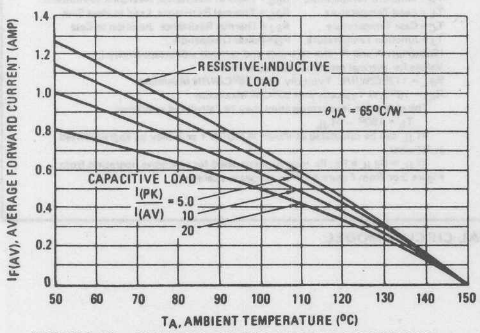


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

SQUARE WAVE INPUT

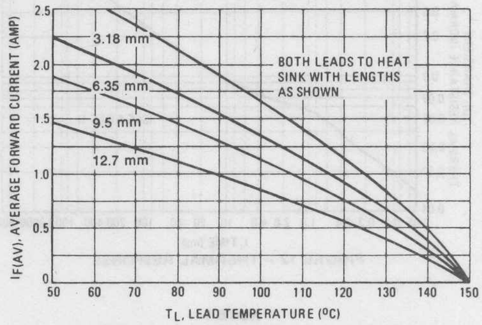


FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

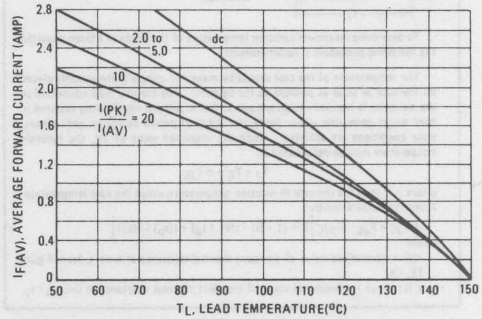


FIGURE 9 — 3.18 mm LEAD LENGTH, VARIOUS LOADS

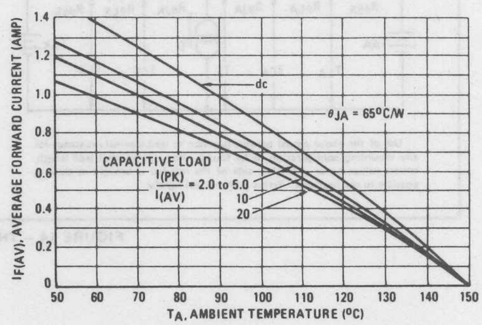


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

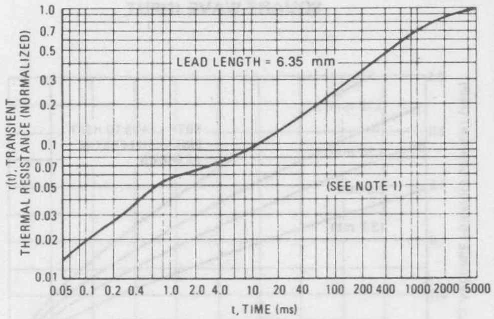


FIGURE 12 – THERMAL RESPONSE

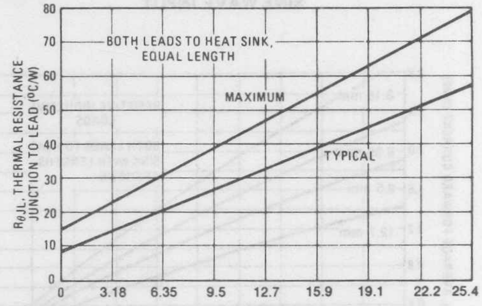
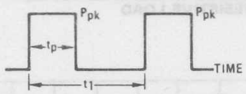


FIGURE 13 – THERMAL RESISTANCE

NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1) \right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 12, i.e.:

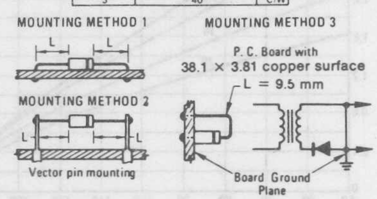
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

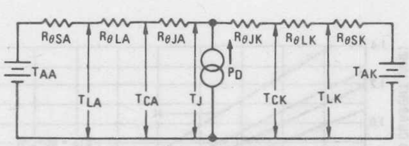
NOTE 2

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L(mm)				
	3.81	6.35	12.7	19.1	$R_{\theta JA}$
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W





Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Power Dissipation
(Subscripts A and K refer to anode and cathode sides respectively.)
Values for thermal resistance components are:
$R_{\theta L}$ = 112°C/W/IN. Typically and 128°C/W/IN Maximum
$R_{\theta J}$ = 18°C/W Typically and 30°C/W Maximum

The maximum lead temperature may be calculated as follows:

$$T_L = 150^\circ - \Delta T_{JL}$$

ΔT_{JL} can be calculated as shown in NOTE 1 or it may be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \bullet P_F$; P_F may be formulated for sine-wave operation from Figure 3 or from Figure 4 for square-wave operation.

FIGURE 14 – THERMAL CIRCUIT MODEL

TYPICAL DYNAMIC CHARACTERISTICS

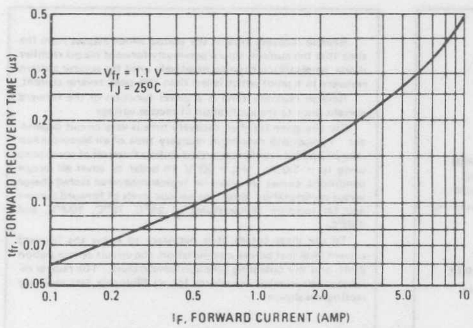


FIGURE 15 – FORWARD RECOVERY TIME

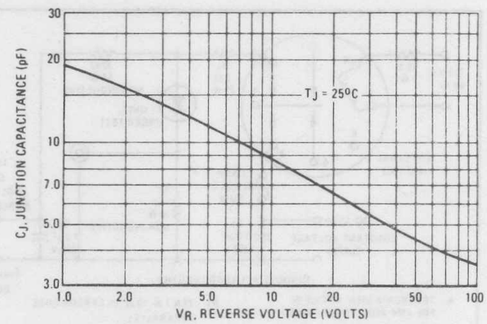


FIGURE 16 – JUNCTION CAPACITANCE

TYPICAL RECOVERED STORED CHARGE DATA
(SEE NOTE 3)

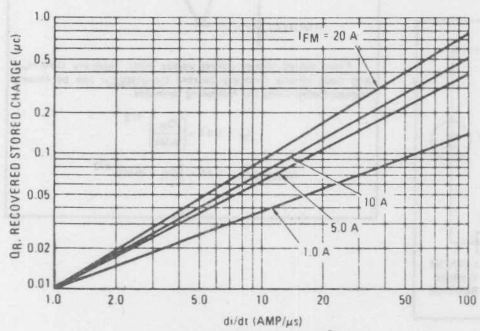


FIGURE 17 – T_J = 25°C

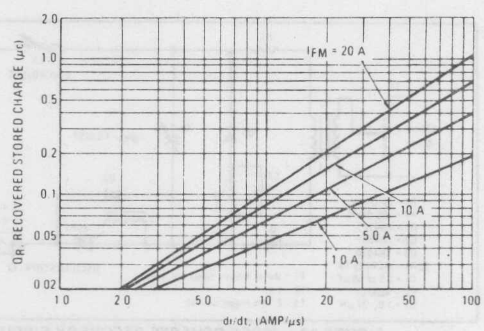


FIGURE 18 – T_J = 75°C

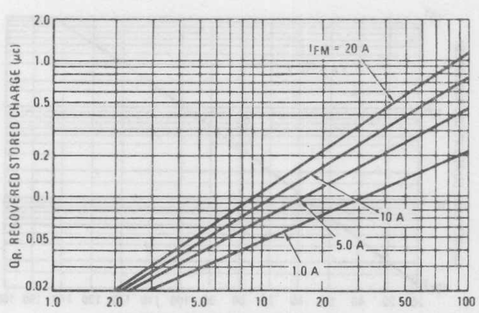


FIGURE 19 – T_J = 100°C

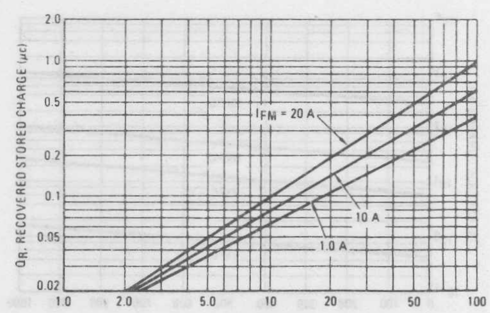


FIGURE 20 – T_J = 150°C

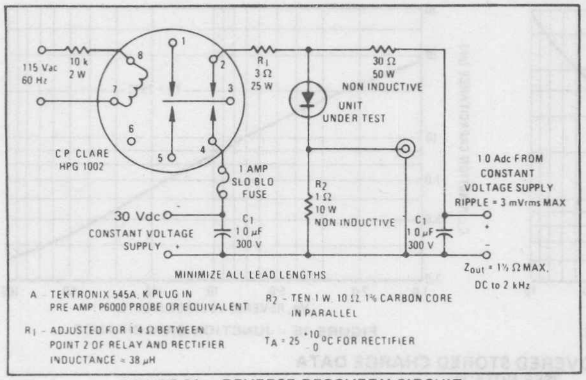


FIGURE 21 – REVERSE RECOVERY CIRCUIT

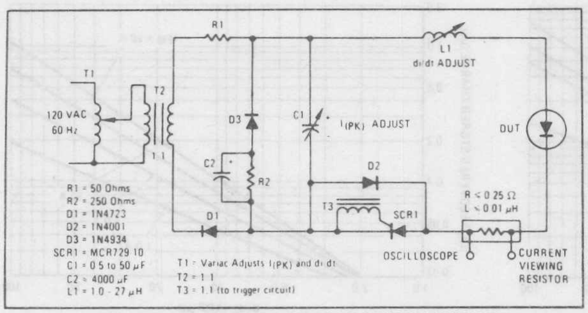


FIGURE 22 – JEDEC REVERSE RECOVERY CIRCUIT

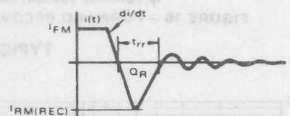
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using $I_F = 1.0$ A, $V_R = 50$ V In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

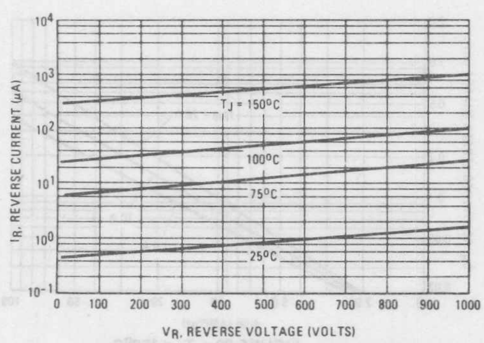


FIGURE 23 – TYPICAL REVERSE LEAKAGE

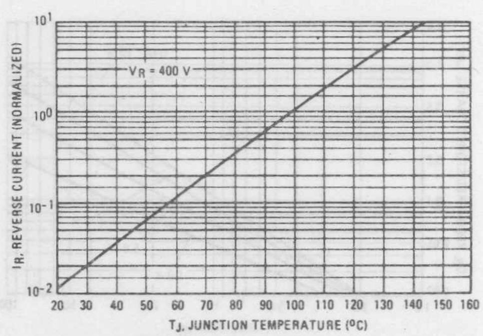


FIGURE 24 – TYPICAL REVERSE LEAKAGE

![MOTOROLA]

MOTOROLA

MBR020
MBR020H
MBR020H1

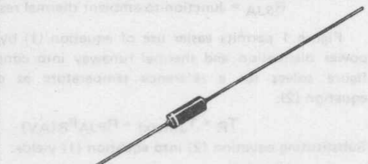
SCHOTTKY RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- DO-7 Glass Package
- Types Available with "TX" Level Testing as the MBR020H and MBR020H1

SCHOTTKY RECTIFIERS

0.5 AMPERE
20 VOLTS



DO-7 Glass

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	14	Volts
Average Rectified Forward Current (V_R(equiv) $\leq$ 0.2 V_R(dc), T_A = 50°C, $R_{\theta JA}$ = 200°C/W, P.C. Board Mounting)	I_O	500	mA
Ambient Temperature (Rated V_R(dc), $P_{F(AV)}$ = 0, $R_{\theta JA}$ = 200°C/W)	T_A	70	°C
Non-Repeptitive Peak Surge Current (Surge applied at rated load conditions, half-wave, single phase 60 Hz, T_A = 70°C)	I_{FSM}	5.0 (for one cycle)	Amp
Operating and Storage Junction Temperature Range (Reverse Voltage applied)	T_J, T_{stg}	−65 to +125	°C
Peak Operating Junction Temperature (Forward Current applied)	$T_{J(pk)}$	150	°C

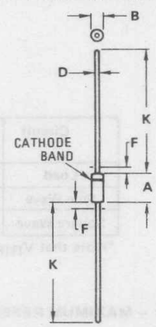
THERMAL CHARACTERISTICS

Characteristic	Symbol	Typical	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	200	°C/W

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Value	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 100 mA) (i_F = 250 mA) (i_F = 500 mA)	v_F	 0.350 0.400 0.500	Volts
Maximum Instantaneous Reverse Current @ Rated dc Voltage (1) (T_L = 25°C) (T_L = 100°C)	i_R	 0.50 5.0	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.84	7.62	0.230	0.300
B	2.16	2.72	0.085	0.107
D	0.46	0.56	0.018	0.022
F	–	1.27	–	0.050
K	25.40	–	1.000	–

All JEDEC dimensions and notes apply

CASE 51-02
DO-204AA
(DO-7)

MECHANICAL CHARACTERISTICS

CASE . . . . Hermetically sealed glass

FINISH . . . . All external surfaces corrosion-resistant and the terminal leads are readily solderable

POLARITY . . . . Cathode indicated by polarity band

MOUNTING POSITIONS . . . . Any

SOLDERING . . . . .220°C 1/16" from case for ten seconds

NOTE 1 – DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.1 V_{RWM}. Proper derating may be accomplished by use of equation (1).

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}P_{F(AV)} - R_{\theta JA}P_{R(AV)} \quad (1)$$

where $T_{A(max)}$ = Maximum allowable ambient temperature
$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest)
$P_{F(AV)}$ = Average forward power dissipation
$P_{R(AV)}$ = Average reverse power dissipation
$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figure 1 permits easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figure solves for a reference temperature as determined by equation (2).

$$T_R = T_{J(max)} - R_{\theta JA}P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figure 1 as a difference in the rate of change of the slope in the vicinity of 105°C. The data of Figure 1 is based upon dc conditions. For use in common rectifier circuits, Table 1 indicates suggested factors for an equivalent dc voltage to use for conservative design, that is:

$$V_{R(equiv)} = V_{in(PK)} \times F \quad (4)$$

The factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

EXAMPLE: Find $T_{A(max)}$ for MBR020 operated in a 12-volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 0.4 A ($I_{F(AV)}$ = 0.2 A), $I_{(FM)}/I_{(AV)}$ = 10, Input Voltage = 10 $V_{(rms)}$, $R_{\theta JA}$ = 200°C/W.

Step 1. Find $V_{R(equiv)}$. Read F = 0.65 from Table 1,
$\therefore V_{R(equiv)} = (1.41)(10)(0.65) = 9.2$ V.

Step 2. Find T_R from Figure 1. Read T_R = 96°C
@ V_R = 9.2 V and $R_{\theta JA}$ = 200°C/W.

Step 3. Find $P_{F(AV)}$ from Figure 2. Read $P_{F(AV)}$ = 0.15 W
@ $\frac{I_{(FM)}}{I_{(AV)}}$ = 10 and $I_{F(AV)}$ = 0.2 A.

Step 4. Find $T_{A(max)}$ from equation (3).
$T_{A(max)} = 96 - (200)(0.15) = 66$°C.

TABLE 1 – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped*†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

*Note that $V_{R(PK)} \approx 2.0\ V_{in(PK)}$. †Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE

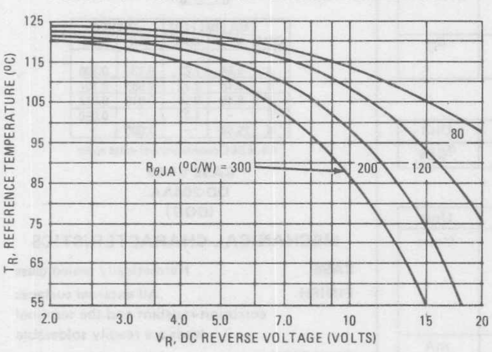
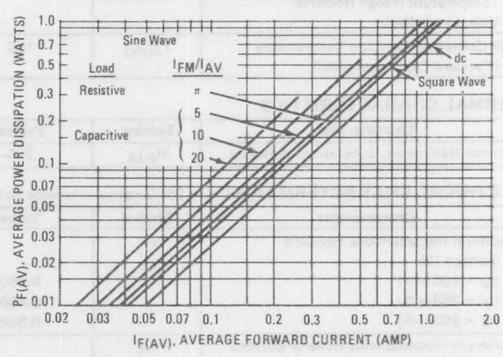


FIGURE 2 – FORWARD POWER DISSIPATION



THERMAL CHARACTERISTICS

FIGURE 3 – THERMAL RESPONSE

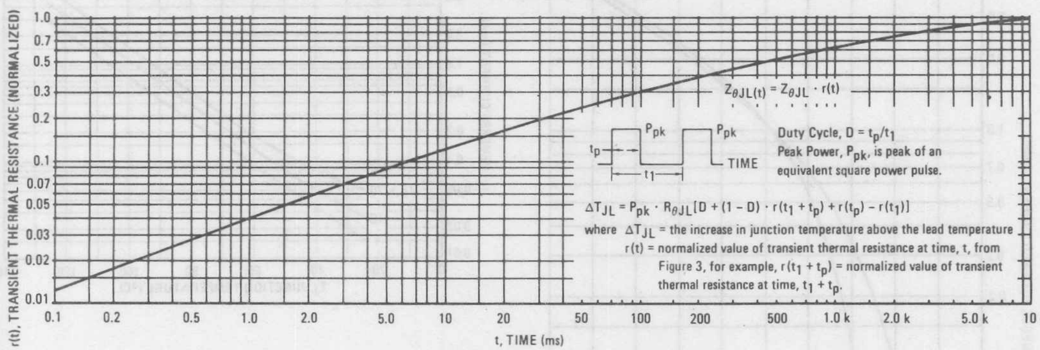
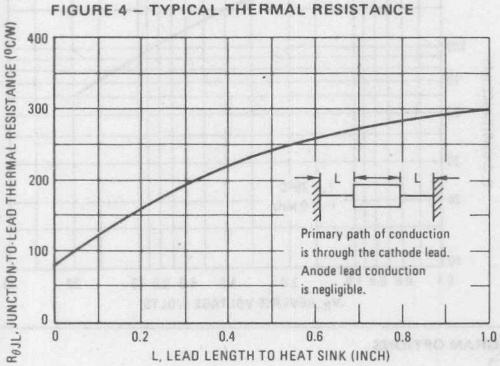


FIGURE 4 – TYPICAL THERMAL RESISTANCE



NOTE 2 – MOUNTING DATA

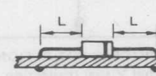
Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering, or in case the tie point temperature cannot be measured.

Values shown for Mounting Methods 1 and 2 apply for normally encountered situations. If the amount of copper is unusually small, $R_{\theta JA}$ can approach 300°C/W. If the cathode lead is tied to an "infinite heat sink", $R_{\theta JL}$ is 80°C/W maximum at a point 1/32" from the cathode end. Heat conduction through the anode lead is negligible.

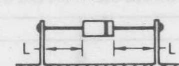
TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

Mounting Method	Lead Length, L (in) 1/4	7/8	$R_{\theta JA}$
1	200	250	°C/W
2	200	250	°C/W
3	120		°C/W

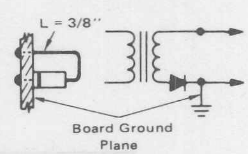
Mounting Method 1
P.C. Board



Mounting Method 2
Vector Pin



Mounting Method 3
P.C. Board with 1-1/2" X 1-1/2" copper surface.



NOTE 3 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 7.)

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

FIGURE 5 – TYPICAL FORWARD VOLTAGE

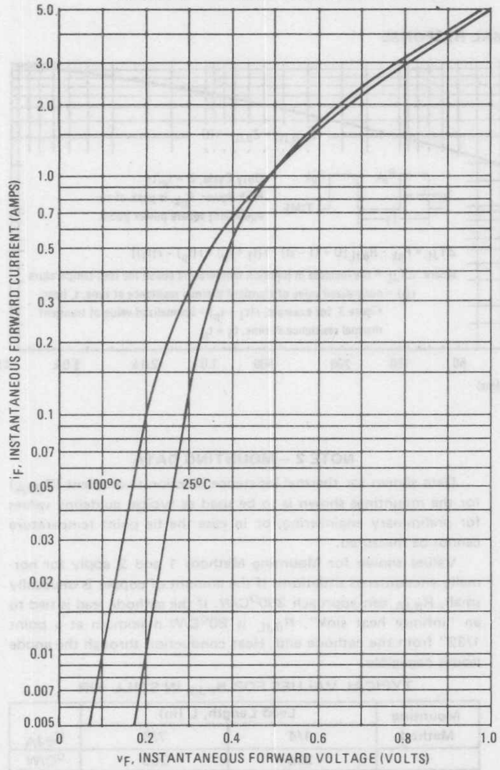


FIGURE 6 – TYPICAL REVERSE CURRENT

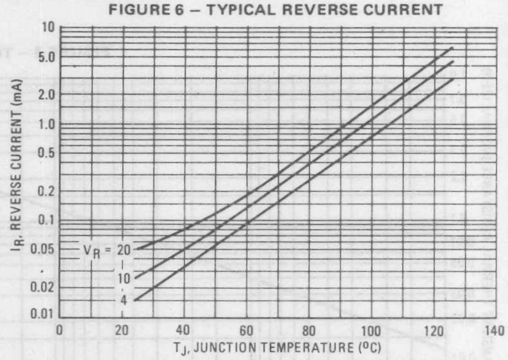
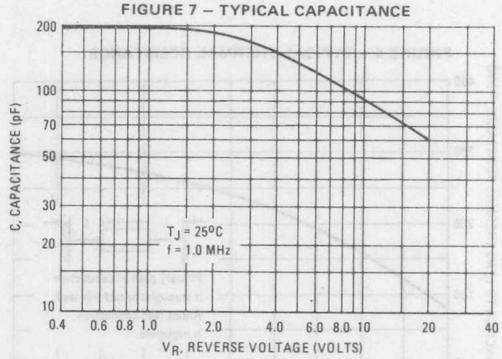
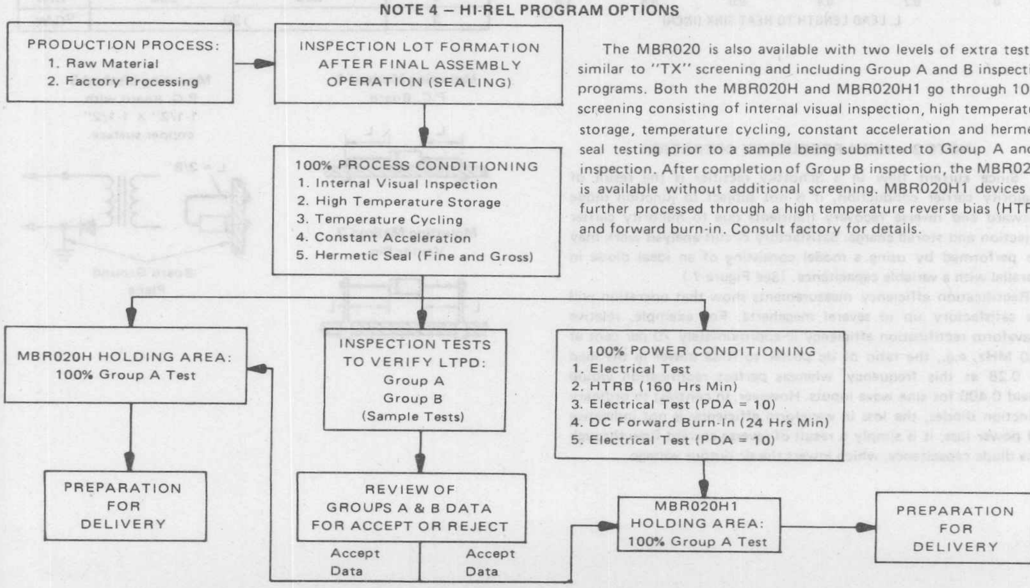


FIGURE 7 – TYPICAL CAPACITANCE



NOTE 4 – HI-REL PROGRAM OPTIONS

The MBR020 is also available with two levels of extra testing similar to "TX" screening and including Group A and B inspection programs. Both the MBR020H and MBR020H1 go through 100% screening consisting of internal visual inspection, high temperature storage, temperature cycling, constant acceleration and hermetic seal testing prior to a sample being submitted to Group A and B inspection. After completion of Group B inspection, the MBR020H is available without additional screening. MBR020H1 devices are further processed through a high temperature reverse bias (HTRB) and forward burn-in. Consult factory for details.



MOTOROLA

MBR320M
MBR330M
MBR340M

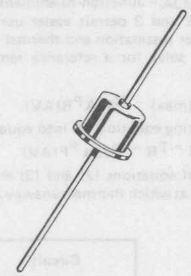
SCHOTTKY BARRIER RECTIFIERS

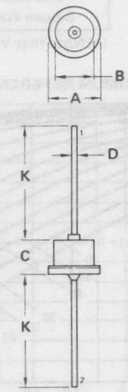
3 AMPERES
20, 30, 40 VOLTS

HOT CARRIER POWER RECTIFIERS

... employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity





DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	–	11.43	–	0.450
B	–	8.89	–	0.350
C	–	7.62	–	0.300
D	1.17	1.42	0.046	0.056
K	24.89	–	0.980	–

CASE 60

MAXIMUM RATINGS

Rating	Symbol	MBR320M	MBR330M	MBR340M	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	Volts
Average Rectified Forward Current $V_{R(equiv)} \leqslant 0.2\ V_R$ (dc), $T_C = 65^oC$ $V_{R(equiv)} \leqslant 0.2\ V_R$ (dc), $T_L = 90^oC$ ($R_{\theta JA} = 25^oC/W$, P.C. Board Mounting, See Note 3)	I_O	← 15 → ← 3.0 →			Amp
Ambient Temperature Rated V_R (dc), $P_{F(AV)} = 0$ $R_{\theta JA} = 25^oC/W$	T_A	65	60	55	^oC
Non-Repetitive Peak Surge Current (surge applied at rated load conditions, halfwave, single phase 60 Hz)	I_{FSM}	← 500 (for 1 cycle) →			Amp
Operating and Storage Junction Temperature Range (Reverse Voltage applied)	T_J, T_{stg}	← -65 to +125 →			^oC
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	← 150 →			^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	3.0	$^oC/W$

ELECTRICAL CHARACTERISTICS ($T_C = 25^oC$ unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 5.0 Amp)	v_F	–	–	0.450	Volts
Maximum Instantaneous Reverse Current @ rated dc Voltage (1) $T_C = 25^oC$ $T_C = 100^oC$	i_R	– –	– –	10 75	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed construction.

FINISH: All external surfaces corrosion-resistant and the terminal leads are readily solderable.

POLARITY: Cathode to case.

MOUNTING POSITIONS: Any

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.1 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA} P_{F(AV)} - R_{\theta JA} P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1, 2 and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA} P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA} P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2 and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2 and 3 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{IN(PK)} \times F \quad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for MBR340M operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 10 A ($I_{F(AV)}$ = 5 A), $I_{(PK)}/I_{(AV)}$ = 10, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 10°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴ $V_{R(equiv)}$ = (1.41)(10)(0.65) = 9.2 V

Step 2: Find T_R from Figure 3. Read T_R = 117°C @ V_R = 9.2 V & $R_{\theta JA}$ = 10°C/W.

Step 3: Find $P_{F(AV)}$ from Figure 4. Read $P_{F(AV)}$ = 6.3 W @ $\frac{I_{(PK)}}{I_{(AV)}}$ = 10 & $I_{F(AV)}$ = 5 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 117-(10)(6.3) = 54°C.

TABLE I — VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped (1), (2)	
Load	Resistive	Capacitive (1)	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

(1) Note that $V_{R(PK)} \approx 2\ V_{in(PK)}$ (2) Use line to center tap voltage for V_{in}.

FIGURE 1 — MAXIMUM REFERENCE TEMPERATURE — MBR320M

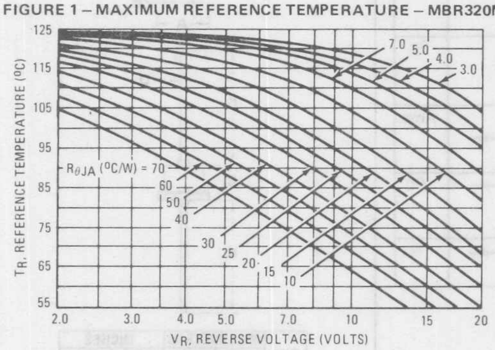


FIGURE 2 — MAXIMUM REFERENCE TEMPERATURE — MBR330M

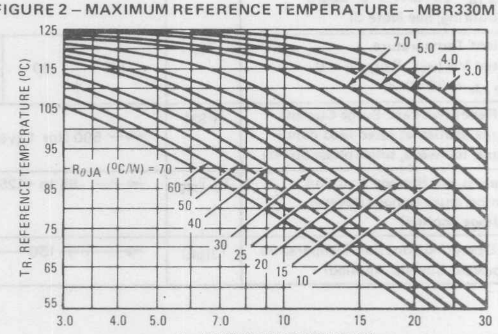


FIGURE 3 — MAXIMUM REFERENCE TEMPERATURE — MBR340M

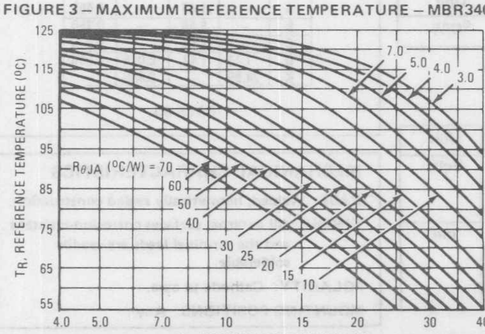
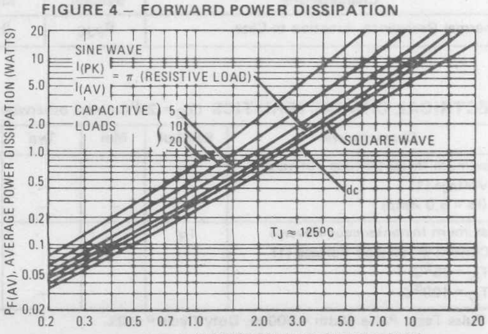


FIGURE 4 — FORWARD POWER DISSIPATION



THERMAL CHARACTERISTICS

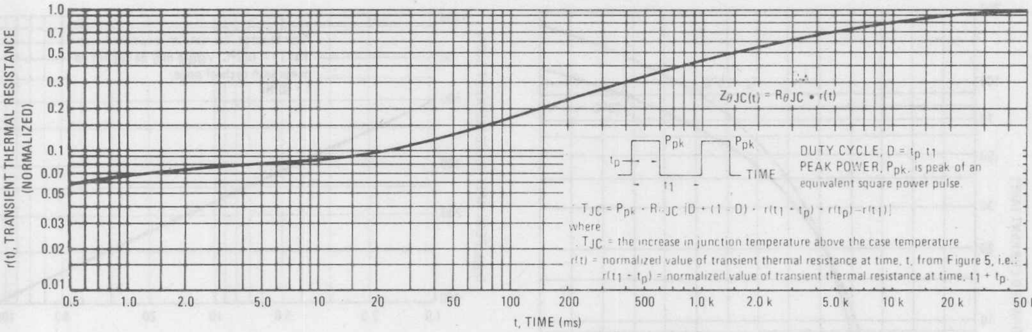
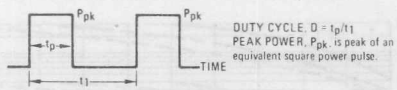


FIGURE 5 – THERMAL RESPONSE

NOTE 2 – FINDING JUNCTION TEMPERATURE



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

r(t) = normalized value of transient thermal resistance at time, t, from Figure 5 i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

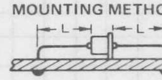
NOTE 3 – MOUNTING DATA

Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering.

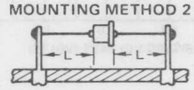
TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN) 1/4	1	$R_{\theta JA}$
1	55	60	°C/W
2	65	70	°C/W
3	25		°C/W

MOUNTING METHOD 1



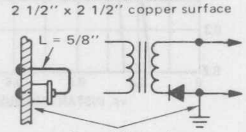
MOUNTING METHOD 2



Vector pin mounting

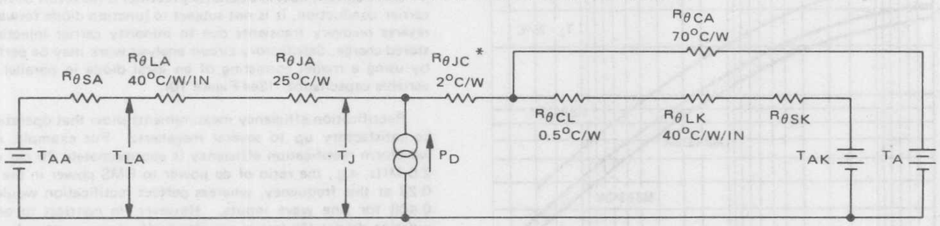
MOUNTING METHOD 3

P. C. Board with 2 1/2″ x 2 1/2″ copper surface



Board Ground Plane

FIGURE 6 – APPROXIMATE THERMAL CIRCUIT MODEL



Use of the above model permits calculation of average junction temperature for any mounting situation. Lowest values of thermal resistance will occur when the cathode lead is brought as close as possible to a heat dissipator; as heat conduction through the anode lead is small. Terms in the model are defined as follows:

***Case temperature reference is at cathode end.**

TEMPERATURES

T_A = Ambient
T_{AA} = Anode Heat Sink Ambient
T_{AK} = Cathode Heat Sink Ambient
T_{LA} = Anode Lead
T_{LK} = Cathode Lead
T_J = Junction

THERMAL RESISTANCES

$R_{\theta CA}$ = Case to Ambient
$R_{\theta SA}$ = Anode Lead Heat Sink to Ambient
$R_{\theta SK}$ = Cathode Lead Heat Sink to Ambient
$R_{\theta LA}$ = Anode Lead
$R_{\theta LK}$ = Cathode Lead
$R_{\theta CL}$ = Case to Cathode Lead
$R_{\theta JC}$ = Junction to Case
$R_{\theta JA}$ = Junction to Anode Lead (S bend)

FIGURE 7 – TYPICAL FORWARD VOLTAGE

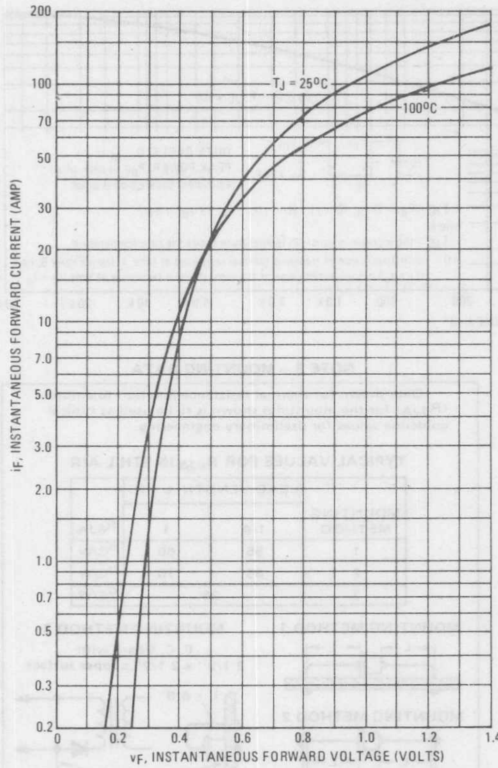


FIGURE 8 – MAXIMUM SURGE CAPABILITY

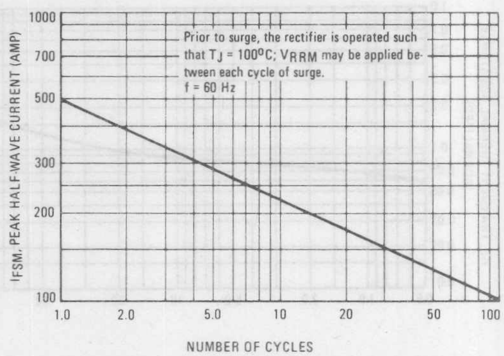


FIGURE 9 – TYPICAL REVERSE CURRENT

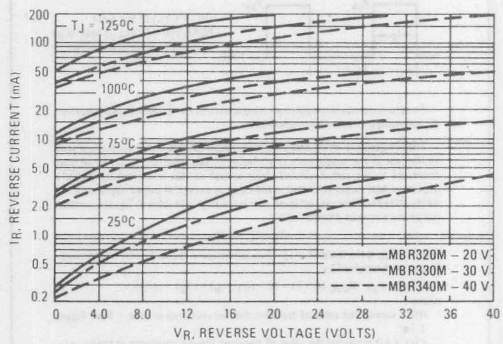
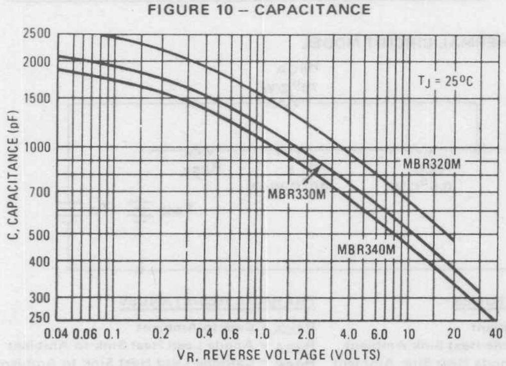


FIGURE 10 – CAPACITANCE



NOTE 4 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 10).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

MOTOROLA

MBR1520
MBR1530
MBR1540

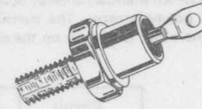
HOT CARRIER POWER RECTIFIER

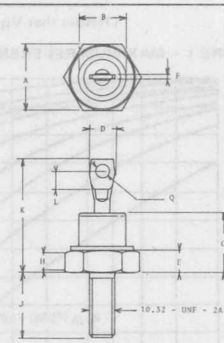
. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity

SCHOTTKY BARRIER RECTIFIERS

15 AMPERE
20,30,40 VOLTS





DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56
DO-4

MAXIMUM RATINGS

Rating	Symbol	MBR1520	MBR1530	MBR1540	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	Volts
Average Rectified Forward Current ($V_{R(equiv)} \leq 0.2\ V_{R(dc)}$, $T_C = 80^oC$	I_O	← 15 →			Amp
Ambient Temperature Rated $V_{R(dc)}$, $P_{F(AV)} = 0$, $R_{\theta JA} = 5.0^oC/W$	T_A	95	90	85	^oC
Non-Repetitive Peak Surge Current (surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	← 500 (for 1 cycle) →			Amp
Operating and Storage Junction Temperature Range (Reverse voltage applied)	T_J, T_{stg}	← -65 to +125 →			^oC
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	← 150 →			^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	2.5	$^oC/W$

ELECTRICAL CHARACTERISTICS ($T_C = 25^oC$ unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 15 Amp)	v_F	–	–	0.550	Volts
Maximum Instantaneous Reverse Current @ rated dc Voltage (1) $T_C = 100^oC$	i_R	– –	– –	10 75	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and terminal lead is readily solderable.

POLARITY: Cathode to Case

MOUNTING POSITION: Any

STUD TORQUE: 15 in. lb. max

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA} P_{F(AV)} - R_{\theta JA} P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1, 2 and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA} P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA} P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2 and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2 and 3 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \quad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for MBR1540 operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 10 A ($I_{F(AV)}$ = 5 A), $I_{(PK)}/I_{(AV)}$ = 20, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 5°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴
$V_{R(equiv)}$ = (1.41)(10)(0.65) = 9.18 V

Step 2: Find T_R from Figure 3. Read T_R = 121°C @ V_R = 9.18 & $R_{\theta JA}$ = 5°C/W

Step 3: Find $P_{F(AV)}$ from Figure 4. Read $P_{F(AV)}$ = 10.5 W @ $\frac{I_{(PK)}}{I_{(AV)}}$ = 20 & $I_{F(AV)}$ = 5 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 121-(5)(10.5) = 68.5°C).

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped(1)(2)	
Load	Resistive	Capacitive(1)	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

(1) Note that $V_{R(PK)} \approx 2\, V_{in(PK)}$

(2) Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE – MBR1520

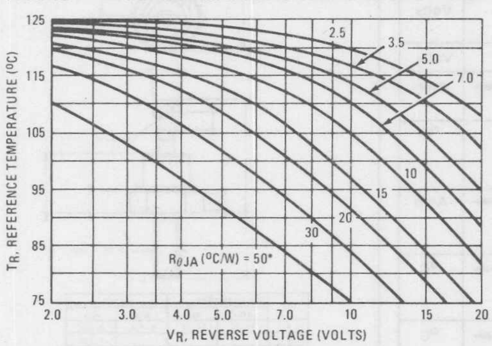


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE – MBR1530

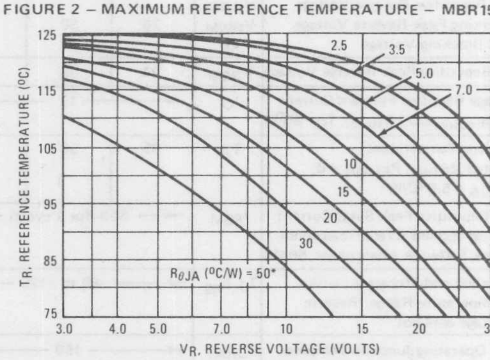
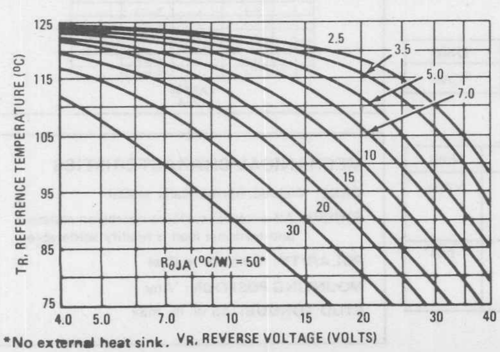


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE – MBR1540



*No external heat sink.

FIGURE 4 – FORWARD POWER DISSIPATION

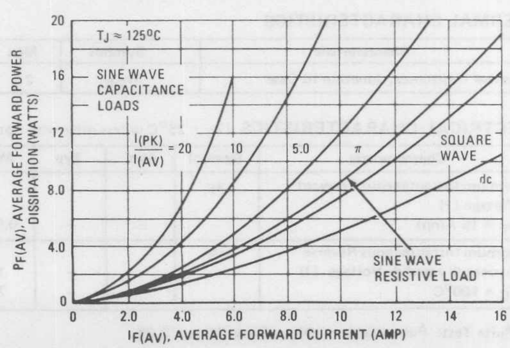


FIGURE 5 – TYPICAL FORWARD VOLTAGE

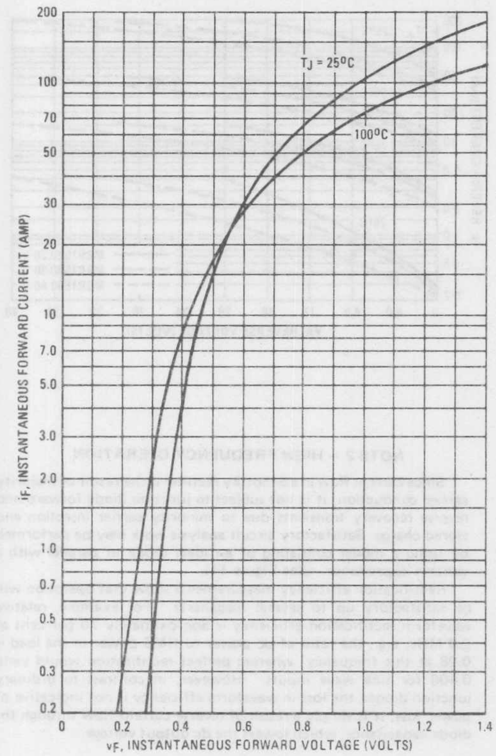


FIGURE 6 – MAXIMUM SURGE CAPABILITY

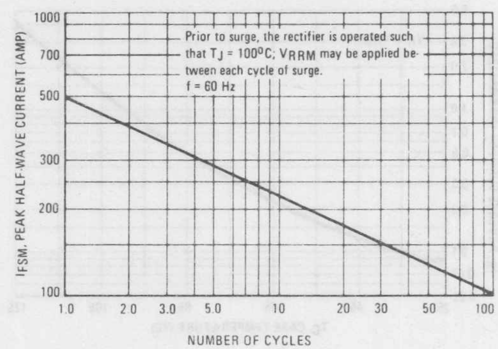


FIGURE 7 – CURRENT DERATING

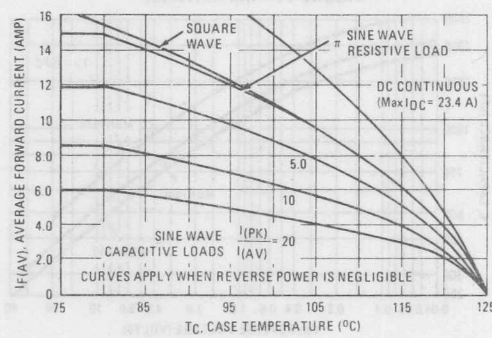


FIGURE 8 – THERMAL RESPONSE

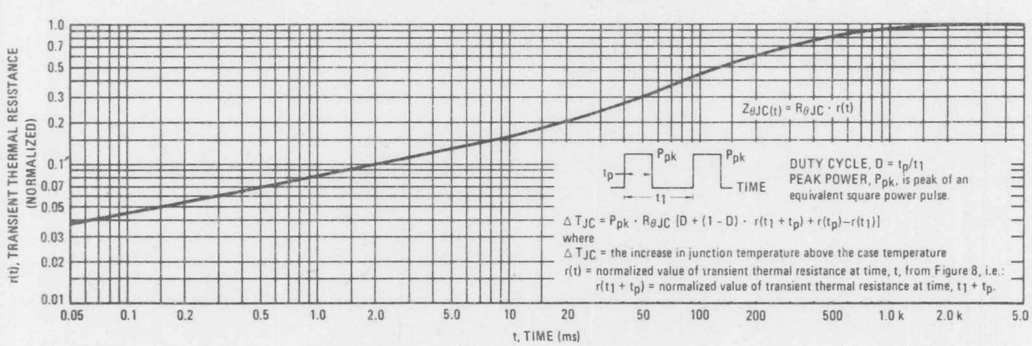


FIGURE 9 – NORMALIZED REVERSE CURRENT

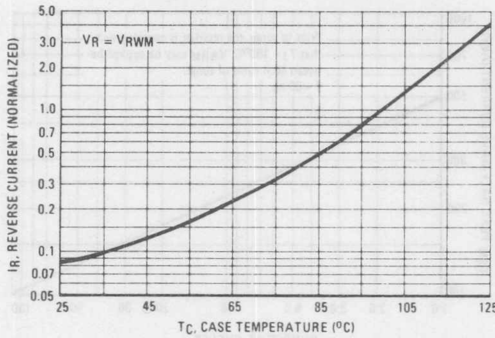


FIGURE 10 – TYPICAL REVERSE CURRENT

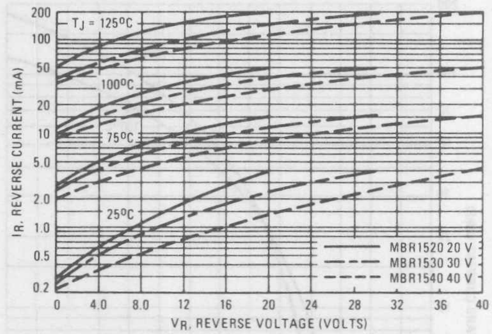
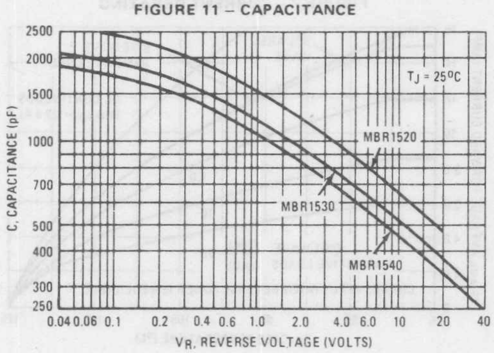


FIGURE 11 – CAPACITANCE



NOTE 2 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 11).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

MOTOROLA

MBR2520
MBR2530
MBR2540

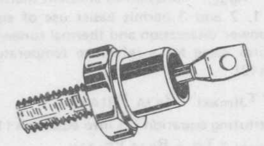
HOT CARRIER POWER RECTIFIER

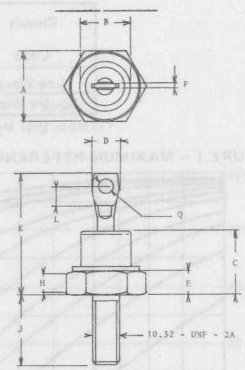
. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity

SCHOTTKY BARRIER RECTIFIERS

25 AMPERE
20, 30, 40 VOLTS





DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56
DO-4

MAXIMUM RATINGS

Rating	Symbol	MBR2520	MBR2530	MBR2540	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	Volts
Average Rectified Forward Current $V_{R(equiv.)} \leqslant 0.2\ V_{R(dc)}$, $T_C = 80^{\circ}C$	I_O	← 25 →			Amp
Ambient Temperature Rated $V_{R(dc)}$, $P_{F(AV)} = 0$ $R_{\theta JA} = 3.5^{\circ}C/W$	T_A	90	85	80	$^{\circ}C$
Non-Repetitive Peak Surge Current (surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	← 800 (for 1 cycle) →			Amp
Operating and Storage Junction Temperature Range (Reverse voltage applied)	T_J, T_{stg}	← -65 to +125 →			$^{\circ}C$
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J\ (pk)}$	← 150 →			$^{\circ}C$

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.75	$^{\circ}C/W$

ELECTRICAL CHARACTERISTICS ($T_C = 25^{\circ}C$ unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 25 Amp)	v_F	—	—	0.550	Volts
Maximum Instantaneous Reverse Current @ Rated dc Voltage (1) ($T_C = 100^{\circ}C$)	i_R	— —	— —	20 150	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed
FINISH: All external surfaces corrosion resistance and terminal lead is readily solderable.
POLARITY: Cathode to Case
MOUNTING POSITIONS: Any
STUD TORQUE: 15 in. lb. Max

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA} P_{F(AV)} - R_{\theta JA} P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JC}$ = Junction-to-ambient thermal resistance

Figures 1, 2 and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA} P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA} P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2 and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2 and 3 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \quad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for MBR2540 operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 16 A ($I_{F(AV)}$ = 8 A), $I_{(PK)}/I_{(AV)}$ = 20, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 5°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴ $V_{R(equiv)}$ = (1.41)(10)(0.65) = 9.18 V

Step 2: Find T_R from Figure 3. Read T_R = 113°C @ V_R = 9.18 & $R_{\theta JA}$ = 5°C/W

Step 3: Find $P_{F(AV)}$ from Figure 4. Read $P_{F(AV)}$ = 14.8 W @ $\frac{I_{(PK)}}{I_{(AV)}}$ = 20 & $I_{F(AV)}$ = 8 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 113-(5)(14.8) = 39°C

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped (1), (2)	
Load	Resistive	Capacitive (1)	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

(1) Note that $V_{R(PK)} \approx 2 V_{in(PK)}$

(2) Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE – MBR2520

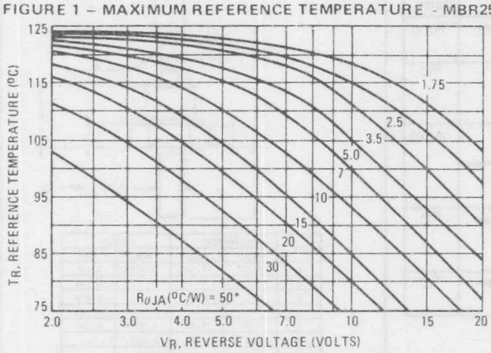


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE – MBR2530

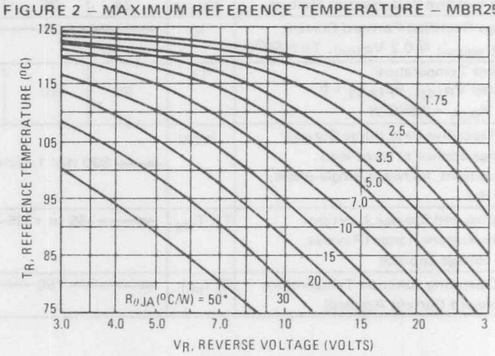


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE – MBR2540

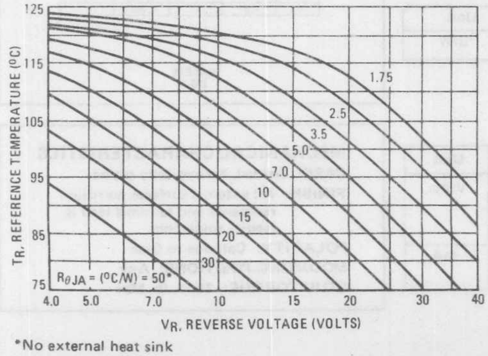
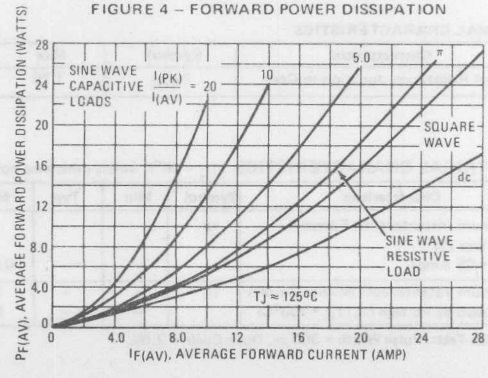


FIGURE 4 – FORWARD POWER DISSIPATION



*No external heat sink

FIGURE 5 — TYPICAL FORWARD VOLTAGE

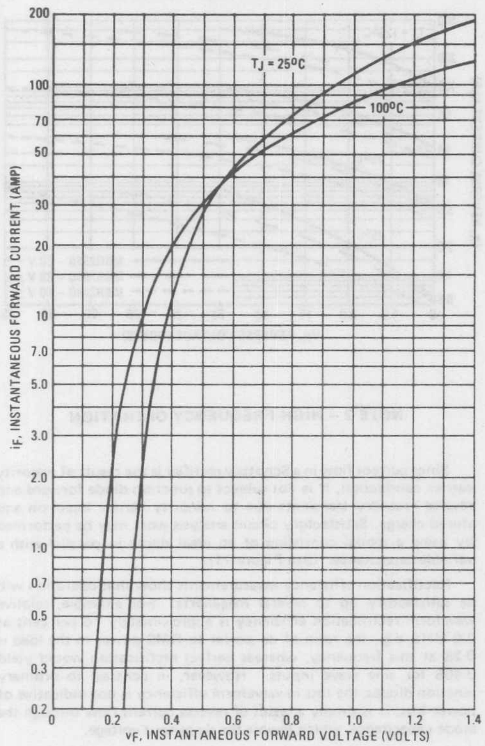


FIGURE 6 — MAXIMUM SURGE CAPABILITY

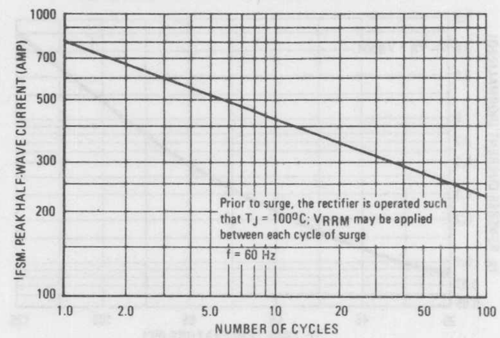


FIGURE 7 — CURRENT DERATING

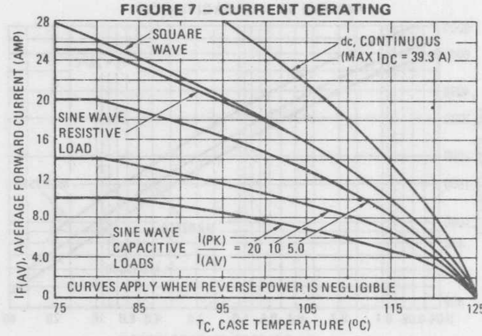


FIGURE 8 — THERMAL RESPONSE

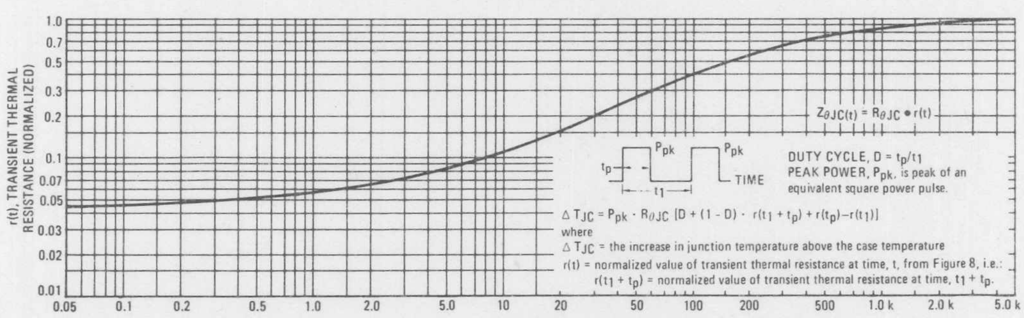


FIGURE 9 – NORMALIZED REVERSE CURRENT

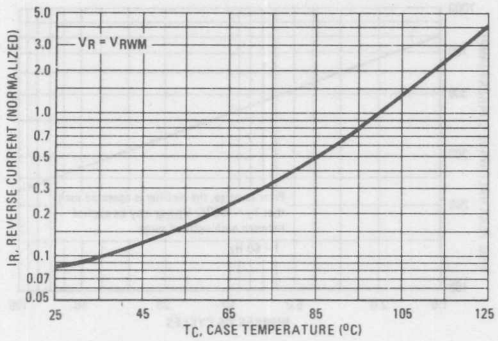


FIGURE 10 – TYPICAL REVERSE CURRENT

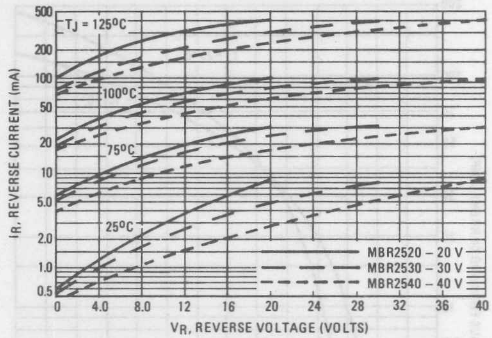
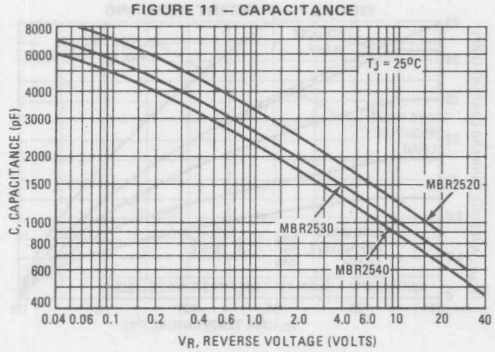


FIGURE 11 – CAPACITANCE



NOTE 2 – HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 11).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

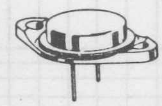
MOTOROLA

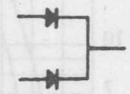
MBR 3020 CT
MBR 3035 CT
MBR 3045 CT

PRODUCT PREVIEW DATA SHEET

SCHOTTKY BARRIER RECTIFIERS

30 AMPERES
20 to 45 VOLTS





Switchmode Power Rectifiers

. . . using the Schottky Barrier principle with a platinum barrier metal. These state-of-the-art devices have the following features:

- Dual diode construction
- Guarding for stress protection
- Low V_f
- 150° C Operating Junction Temperature

MAXIMUM RATINGS PER DIODE

Rating	Symbol	MBR3020CT	MBR3035CT	MBR3045CT	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	35	45	Volts
Average Rectified Forward Current (Rated V_R) $T_c = 95°C$	I_O		30		Amp
Case Temperature (Rated V_R)	T_C		145		°C
Non-repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}		400		Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}		-65 to +150		°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$		175		°C
Voltage Rate of Change (Rated V_R)	dv/dt		1000		v/μs

THERMAL CHARACTERISTICS PER DIODE

Characteristic	Symbol	MBR3020CT	MBR3035CT	MBR3045CT	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.4	1.4	1.4	°C/W

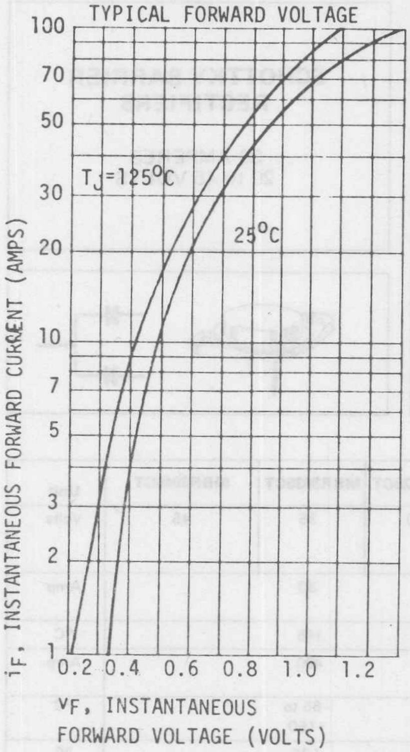
ELECTRICAL CHARACTERISTICS PER DIODE

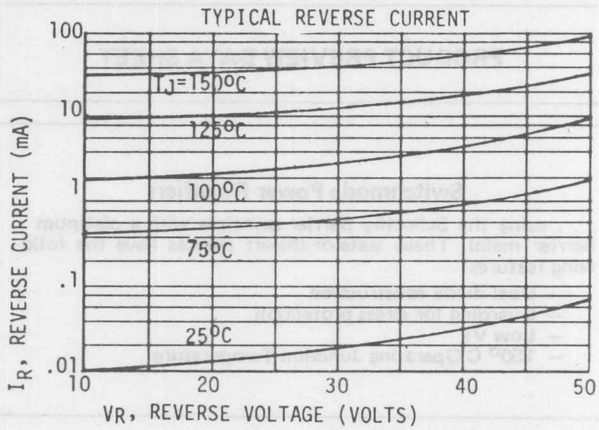
Characteristic	Symbol	MBR3020CT	MBR3035CT	MBR3045CT	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 20 Amp, T_C = 125°C) (i_F = 60 Amp, T_C = 125°C) (i_F = 60 Amp, T_C = 25°C)	v_F	 .60 .95 1.00	 .60 .95 1.00	 .60 .95 1.00	Volts
Maximum Instantaneous Reverse Current (1) (Rated dc Voltage, T_C = 125°C) (Rated dc Voltage, T_C = 25°C)	i_R	 60 1.0	 60 1.0	 60 1.0	mA
Capacitance	C_t	2000	2000	2000	pF

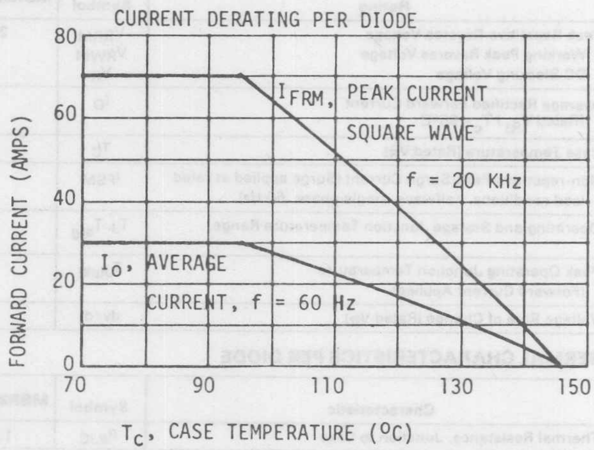
(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

This is advance information on a new introduction and specificatione are subject to change without notice

MBR 3020 CT, MBR 3035 CT, MBR 3045 CT

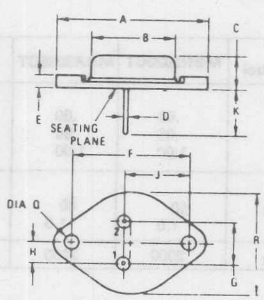






DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	-	39.37	-	1.550
B	-	21.08	-	0.830
C	6.35	7.62	0.250	0.300
D	0.99	1.09	0.039	0.043
E	-	3.43	-	0.135
F	29.90	30.40	1.177	1.197
G	10.67	11.18	0.420	0.440
H	5.33	5.59	0.210	0.220
J	16.64	17.15	0.655	0.675
K	11.18	12.19	0.440	0.480
Q	3.84	4.09	0.151	0.161
R	-	26.67	-	1.050

CASE 11-01
TO-3



CATHODES TO CASE

MOTOROLA

MBR3520 MBR3535
MBR3545
MBR3545H, H1

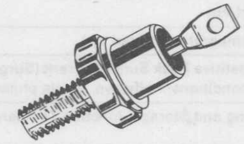
SWITCHMODE POWER RECTIFIERS

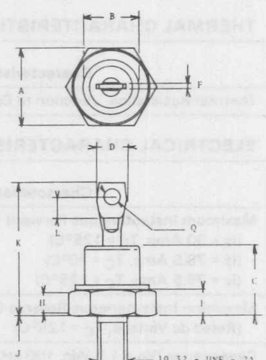
. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free-wheeling diodes, and polarity-protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- TX Version Available
- Low Power Loss/High Efficiency
- High Surge Capacity

SCHOTTKY BARRIER RECTIFIERS

35 AMPERES
20 to 45 VOLTS

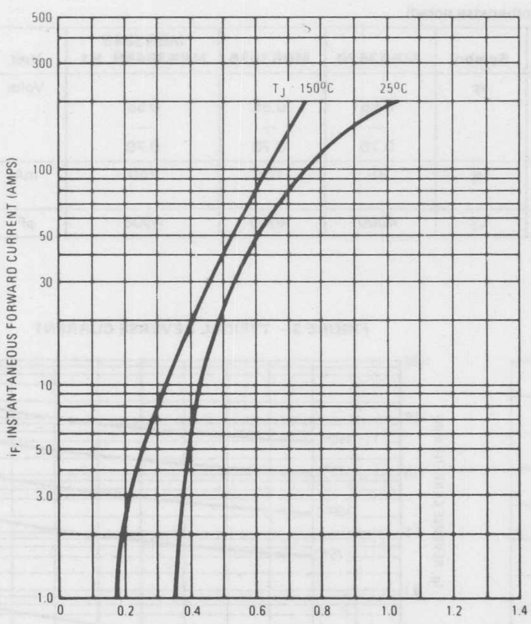




DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10.77	11.10	0.424	0.437
B				0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56.
DO-4

FIGURE 1 – TYPICAL FORWARD VOLTAGE



MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion-resistant and terminal leads are readily solderable.

POLARITY: Cathode to case

MOUNTING POSITIONS: Any

STUD TORQUE: 15 in. lb. max

MBR3520, MBR3535, MBR3545, MBR3545H, H1

MAXIMUM RATINGS

Rating	Symbol	MBR3520	MBR3535	MBR3545 MBR3545H, H1	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	35	45	Volts
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20 kHz)	I_{FRM}	70 T_C = 90°C	70 T_C = 90°C	70 T_C = 90°C	Amp
Average Rectified Forward Current (Rated V_R)	I_O	30 T_C = 90°C	30 T_C = 90°C	30 T_C = 90°C	Amp
Case Temperature (Rated V_R)	T_C	140	140	140	°C
Non-repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	600	600	600	Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +150	−65 to +150	−65 to +150	°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	175	175	175	°C
Voltage Rate of Change (Rated V_R)	dv/dt	1000	1000	1000	v/μs

THERMAL CHARACTERISTICS

Characteristic	Symbol	MBR3520	MBR3535	MBR3545 MBR3545H, H1	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	←	2.0	→	°C/W

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	MBR3520	MBR3535	MBR3545 MBR3545H, H1	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 30 Amp, T_C = 125°C) (i_F = 78.5 Amp, T_C = 70°C) (i_F = 78.5 Amp, T_C = 125°C)	v_F	 0.55 — 0.70	 0.55 — 0.70	 0.55 — 0.70	Volts
Maximum Instantaneous Reverse Current (1) (Rated dc Voltage, T_C = 125°C)	i_R	75	100	150	mA
Capacitance (V_R = 1.0 Vdc, 100 kHz ≥ f ≥ 1.0 MHz)	C_t	4000	4000	4000	pF

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

FIGURE 2 — CURRENT DERATING

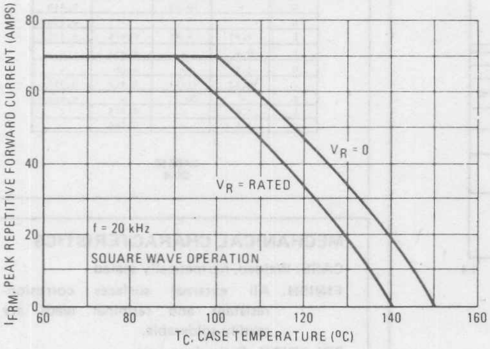
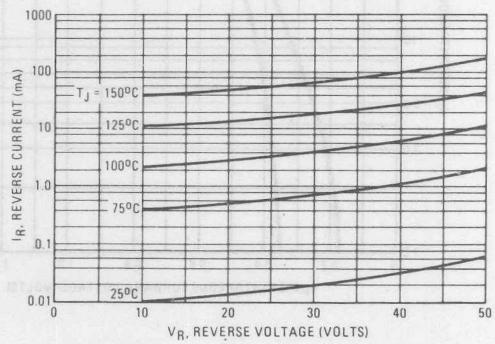
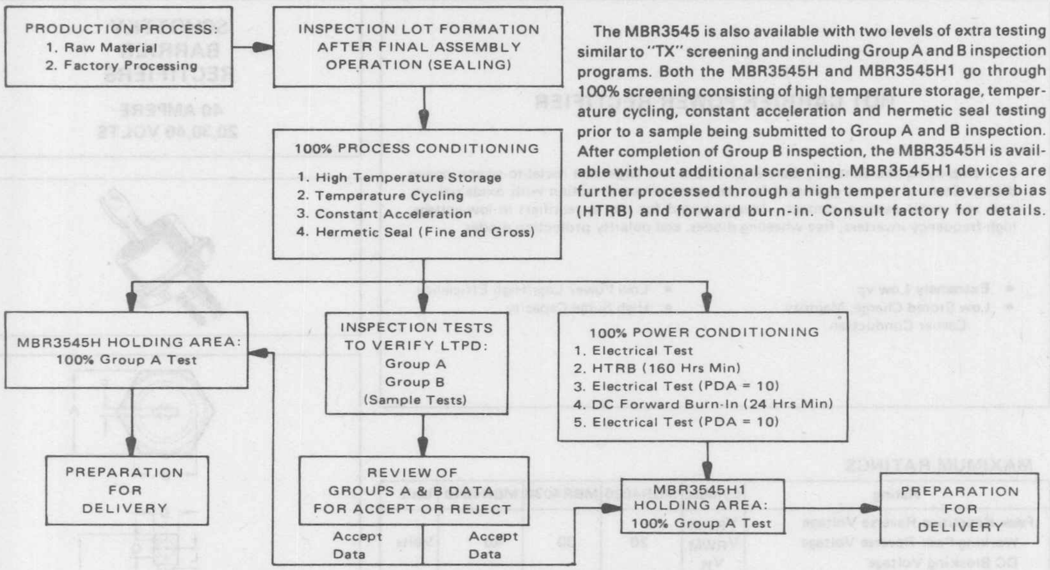


FIGURE 3 — TYPICAL REVERSE CURRENT



NOTE 1 – HI-REL PROGRAM OPTIONS

The MBR3545 is also available with two levels of extra testing similar to "TX" screening and including Group A and B inspection programs. Both the MBR3545H and MBR3545H1 go through 100% screening consisting of high temperature storage, temperature cycling, constant acceleration and hermetic seal testing prior to a sample being submitted to Group A and B inspection. After completion of Group B inspection, the MBR3545H is available without additional screening. MBR3545H1 devices are further processed through a high temperature reverse bias (HTRB) and forward burn-in. Consult factory for details.



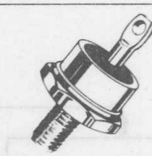
![MOTOROLA]

MOTOROLA

MBR4020
MBR4030
MBR4040

SCHOTTKY BARRIER RECTIFIERS

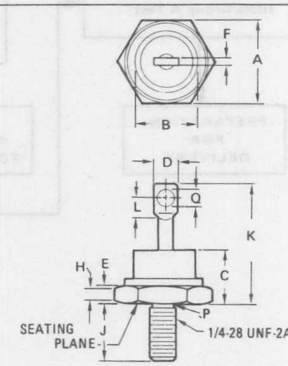
40 AMPERE
20,30,40 VOLTS



HOT CARRIER POWER RECTIFIER

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.86	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

MAXIMUM RATINGS

Rating	Symbol	MBR4020	MBR4030	MBR4040	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	40	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	48	Volts
Average Rectified Forward Current $V_{R(equiv)} \leq 0.2\ V_{R(dc)}$, $T_C = 70^{\circ}C$	I_O	← 40 →			Amp
Ambient Temperature Rated $V_{R(dc)}$, $P_{F(AV)} = 0$, $R_{\theta JA} = 2.0^{\circ}C/W$	T_A	100	95	90	$^{\circ}C$
Non-Repetitive Peak Surge Current (surge applied at rated load conditions halfwave, single phase, 60 Hz)	I_{FSM}	← 800 (for 1 cycle) →			Amp
Operating and Storage Junction Temperature Range (Reverse voltage applied)	T_J, T_{stg}	← -65 to +125 →			$^{\circ}C$
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	← 150 →			$^{\circ}C$

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.0	$^{\circ}C/W$

ELECTRICAL CHARACTERISTICS ($T_C = 25^{\circ}C$ unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 40 Amp)	v_F	–	–	0.630	Volts
Maximum Instantaneous Reverse Current @ rated dc Voltage (1) $T_C = 100^{\circ}C$	i_R	– –	– –	20 150	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and terminal lead is readily solderable.

POLARITY: Cathode to Case

MOUNTING POSITION: Any

STUD TORQUE: 25 in. lb. Max

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA} P_{F(AV)} - R_{\theta JA} P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JC}$ = Junction-to-ambient thermal resistance

Figures 1, 2 and 3 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA} P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA} P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1, 2 and 3 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1, 2 and 3 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \quad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for MBR4040 operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 30 A ($I_{F(AV)}$ = 15 A), $I_{(PK)}/I_{(AV)}$ = 10, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 3°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴
$V_{R(equiv)}$ = (10)(1.41)(0.65) = 9.18 V

Step 2: Find T_R from Figure 3. Read T_R = 118°C @ V_R = 9.18 V & $R_{\theta JA}$ = 3°C/W

Step 3: Find $P_{F(AV)}$ from Figure 4. Read $P_{F(AV)}$ = 25 W @ $\frac{I_{(PK)}}{I_{(AV)}}$ = 10 & $I_{F(AV)}$ = 15 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 118-(3)(25) = 43°C.

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped (1),(2)	
Load	Resistive	Capacitive (1)	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

(1) Note that $V_{R(PK)} \approx 2\ V_{in(PK)}$

(2) Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE – MBR4020

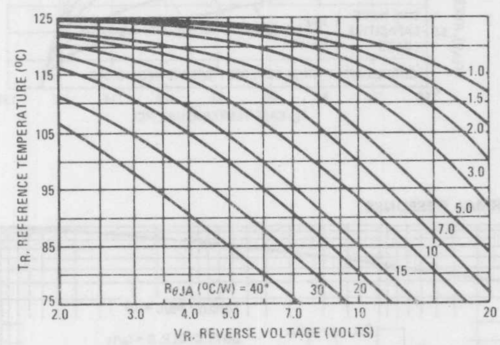


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE – MBR4030

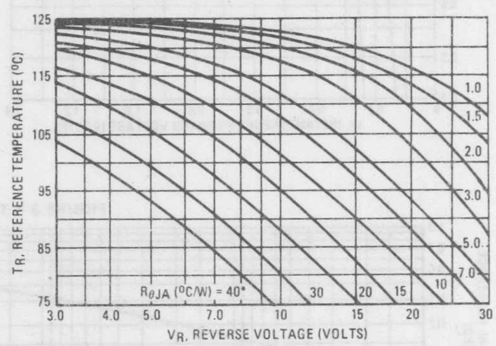
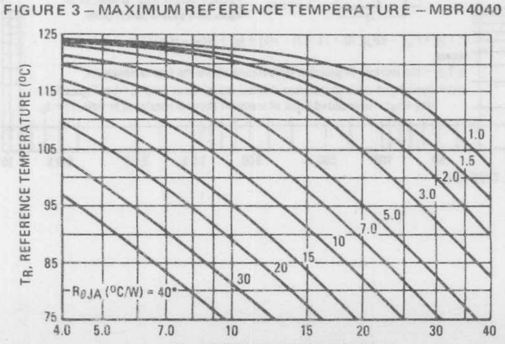


FIGURE 3 – MAXIMUM REFERENCE TEMPERATURE – MBR4040



*No external heat sink

FIGURE 4 – FORWARD POWER DISSIPATION

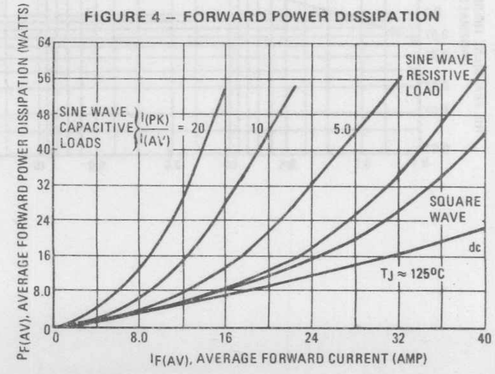


FIGURE 5 – TYPICAL FORWARD VOLTAGE

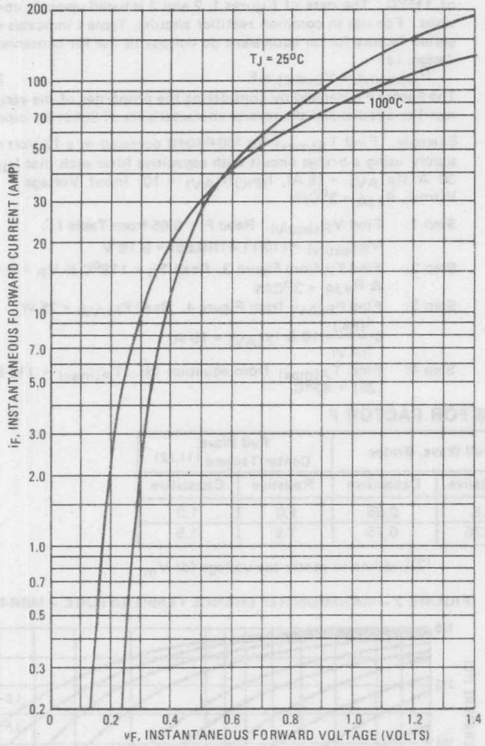


FIGURE 6 – MAXIMUM SURGE CAPABILITY

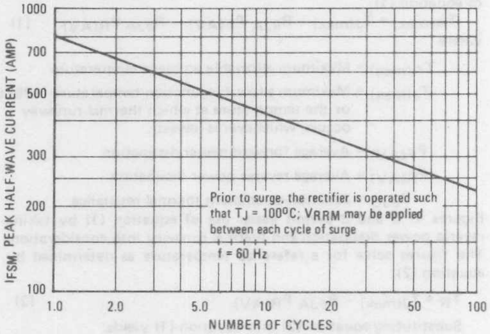


FIGURE 7 – CURRENT DERATING

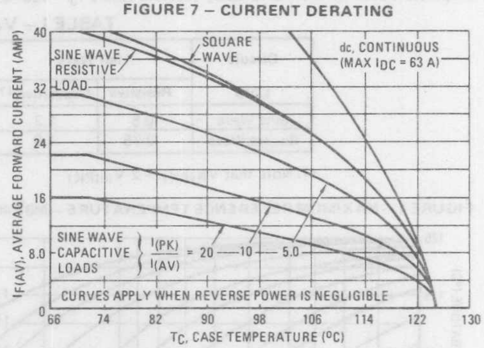


FIGURE 8 – THERMAL RESPONSE

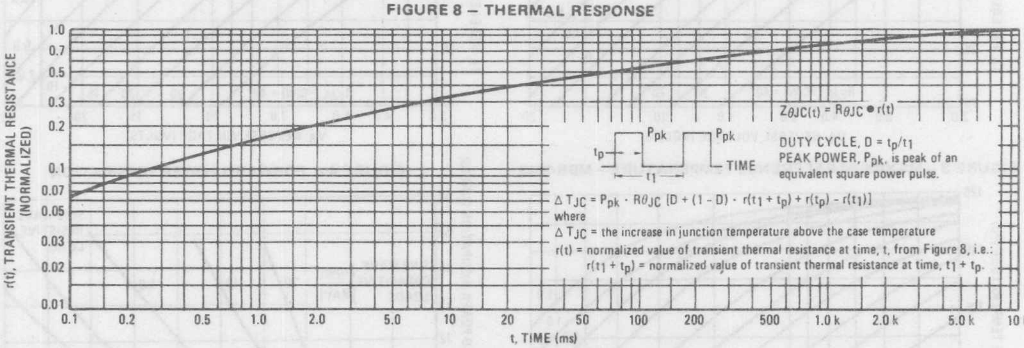


FIGURE 9 – NORMALIZED REVERSE CURRENT

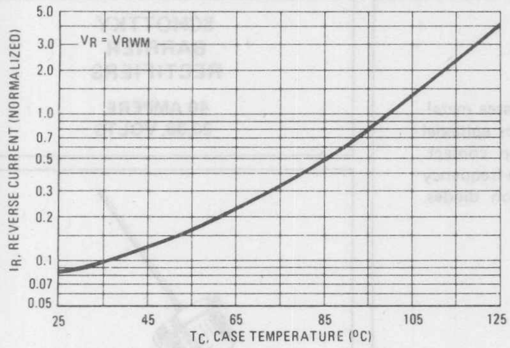


FIGURE 10 – TYPICAL REVERSE CURRENT

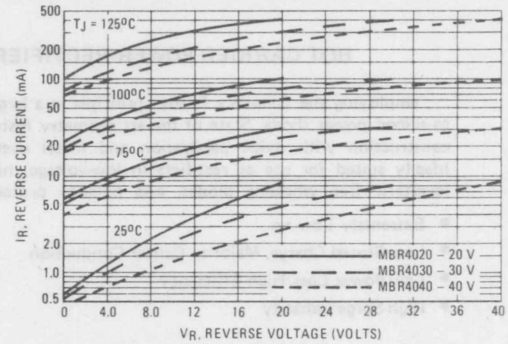
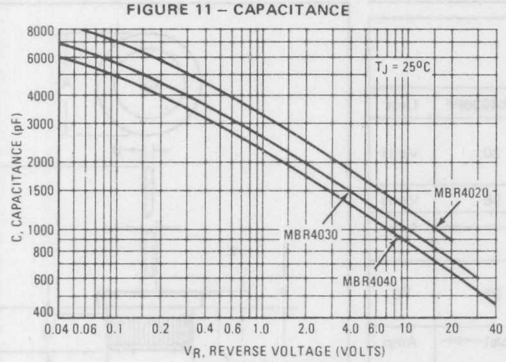


FIGURE 11 – CAPACITANCE



NOTE 2: HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 11).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

NOTE 3: SOLDER HEAT

The excellent heat transfer property of the heavy duty copper anode terminal which transmits heat away from the die requires that caution be used when attaching wires. Motorola suggests a heat sink be clamped between the eyelet and the body during any soldering operation.

MOTOROLA

MBR4020PF
MBR4030PF

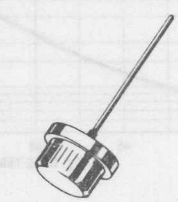
SCHOTTKY BARRIER RECTIFIERS

40 AMPERE
20,30, VOLTS

HOT CARRIER POWER RECTIFIER

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- Low Power Loss/High Efficiency
- High Surge Capacity



MAXIMUM RATINGS

Rating	Symbol	MBR4020PF	MBR4030PF	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	24	36	Volts
Average Rectified Forward Current $V_{R(equiv)} \leqslant 0.2\ V_{R(dc)}, T_C = 50^\circ C$	I_O	← 40 →		Amp
Ambient Temperature Rated $V_{R(dc)}, P_{F(AV)} = 0,$ $R_{\theta JA} = 2.0^\circ C/W$	T_A	100	95	$^\circ C$
Non-Repetitive Peak Surge Current (surge applied at rated load conditions halfwave, single phase, 60 Hz)	I_{FSM}	← 800 (for 1 cycle) →		Amp
Operating and Storage Junction Temperature Range (Reverse voltage applied)	T_J, T_{stg}	← -65 to +125 →		$^\circ C$
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	← 150 →		$^\circ C$

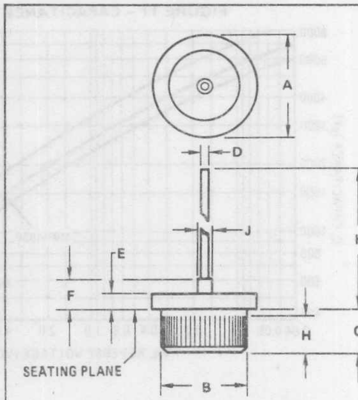
THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.3	$^\circ C/W$

ELECTRICAL CHARACTERISTICS ($T_C = 25^\circ C$ unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 40 Amp)	v_F	–	0.57	0.630	Volts
Maximum Instantaneous Reverse Current @ rated dc Voltage (1) $T_C = 100^\circ C$	i_R	– –	– –	20 150	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	15.494	16.256	0.610	0.640
B	12.725	12.827	0.501	0.505
C	5.08	6.35	0.200	0.250
D	1.193	1.346	0.047	0.053
E	2.032	4.826	0.080	0.190
F	–	10.77	–	0.424
H	4.572	6.350	0.180	0.250
J	–	3.556	–	0.140
K	12.70	–	0.500	–

CASE 43-02
DO-21

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and terminal lead is readily solderable.

POLARITY: Cathode to Case

MOUNTING POSITION: Any

WEIGHT: 9 grams (Approximately)

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA} P_{F(AV)} - R_{\theta JA} P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (125°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1 and 2 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA} P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA} P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 125°C, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figures 1 and 2 as a difference in the rate of change of the slope in the vicinity of 115°C. The data of Figures 1 and 2 is based upon dc conditions. For use in common rectifier circuits, Table I indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \quad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the reverse characteristics of Schottky diodes.

Example: Find $T_{A(max)}$ for MBR4030PF operated in a 12-Volt dc supply using a bridge circuit with capacitive filter such that I_{DC} = 30 A ($I_{F(AV)}$ = 15 A), $I_{(FM)}/I_{(AV)}$ = 10, Input Voltage = 10 V(rms), $R_{\theta JA}$ = 3°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 0.65 from Table I ∴
$V_{R(equiv)}$ = (10)(1.41)(0.65) = 9.18 V

Step 2: Find T_R from Figure 2. Read T_R = 118°C @ V_R = 9.18 V & $R_{\theta JA}$ = 3°C/W

Step 3: Find $P_{F(AV)}$ from Figure 3. Read $P_{F(AV)}$ = 25 W
@ $I_{(FM)}/I_{(AV)}$ = 10 & $I_{F(AV)}$ = 15 A

Step 4: Find $T_{A(max)}$ from equation (3).
$T_{A(max)}$ = 118-(3) (25) = 43°C.

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave, Center Tapped (1),(2)	
Load	Resistive	Capacitive (1)	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.5	1.3	0.5	0.65	1.0	1.3
Square Wave	0.75	1.5	0.75	0.75	1.5	1.5

(1) Note that $V_{R(RM)} \approx 2\ V_{in(PK)}$

(2) Use line to center tap voltage for V_{in}

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE–MBR4020PF

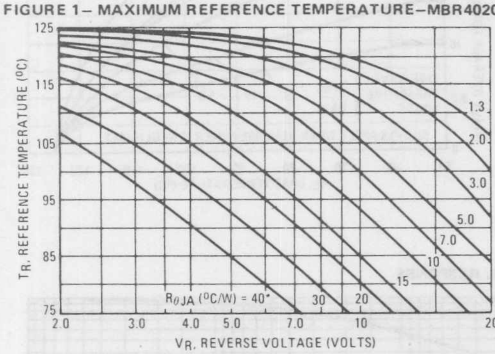
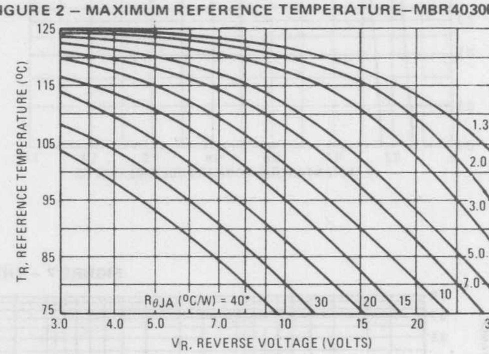


FIGURE 2 – MAXIMUM REFERENCE TEMPERATURE–MBR4030PF



*No external heat sink.

FIGURE 3 – FORWARD POWER DISSIPATION

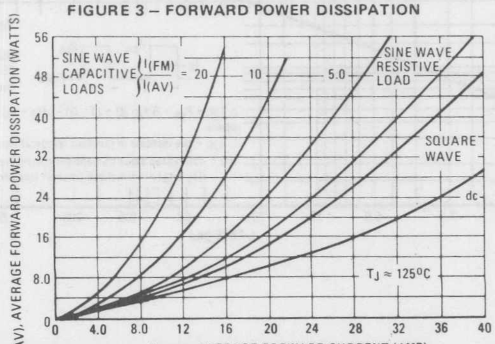


FIGURE 4 – TYPICAL FORWARD VOLTAGE

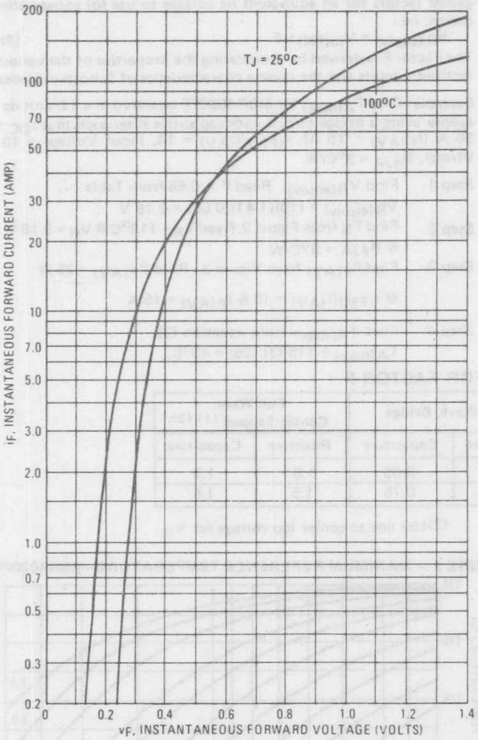


FIGURE 5 – MAXIMUM NON-REPETITIVE SURGE CAPABILITY

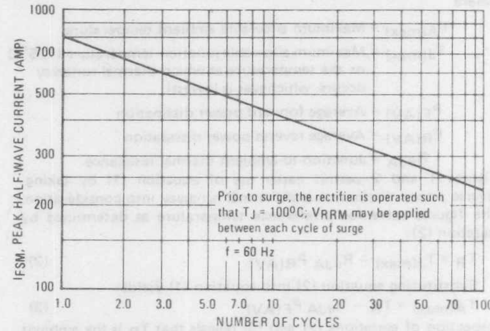


FIGURE 6 – CURRENT DERATING

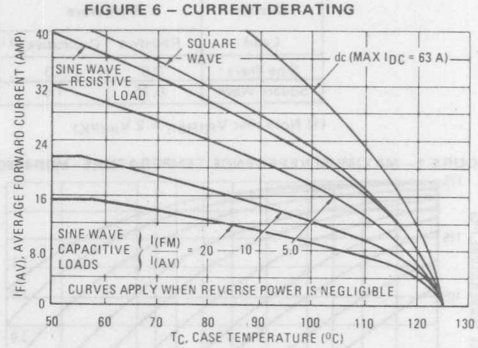


FIGURE 7 – THERMAL RESPONSE

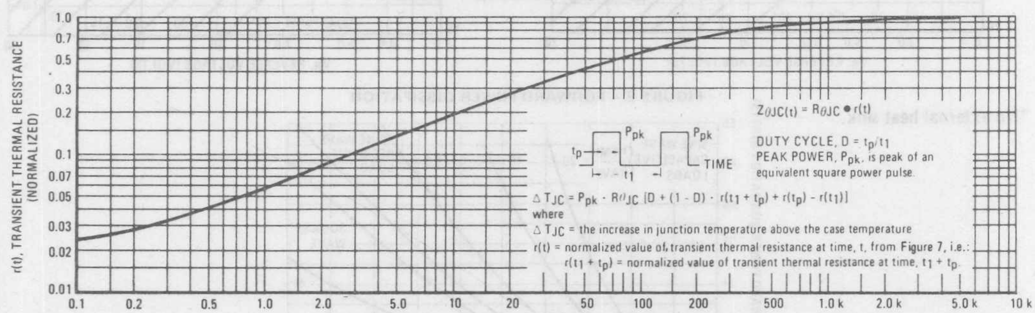


FIGURE 8 – NORMALIZED REVERSE CURRENT

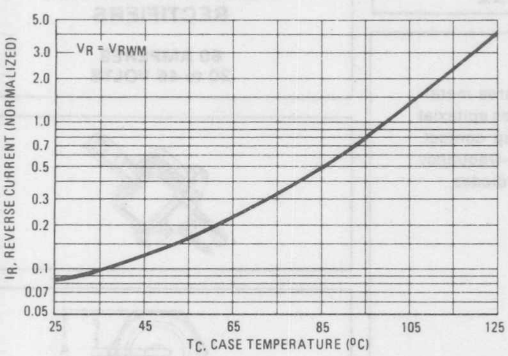


FIGURE 9 – TYPICAL REVERSE CURRENT

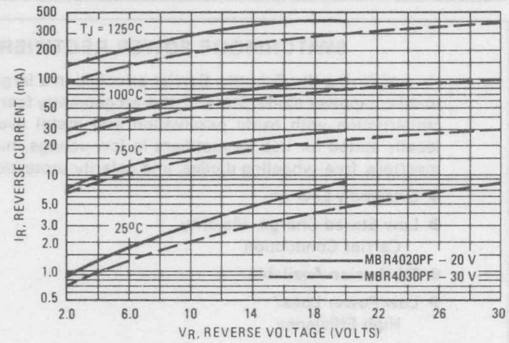
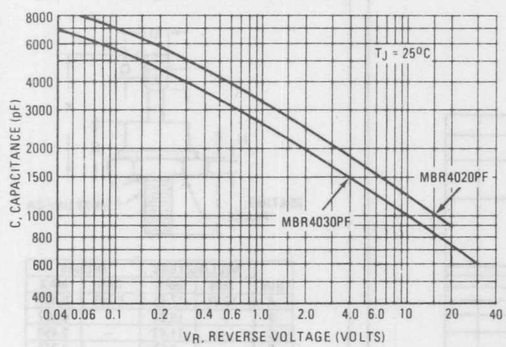


FIGURE 10 – CAPACITANCE



NOTE 2 HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 10).

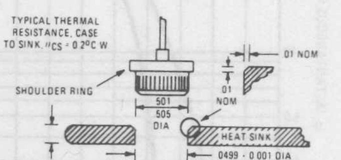
Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

MOUNTING INFORMATION

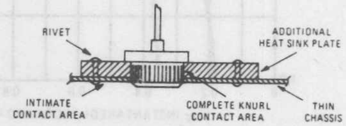
Recommended procedures for mounting are as follows:

1. Drill a hole in the heat sink 0.499 ± 0.001 inch in diameter.
2. Break the hole edge as shown to provide a guide into the hole and prevent shearing off the knurled side of the rectifier.
3. The depth and width of the break should be 0.010 inch maximum to retain maximum heat sink surface contact.
4. To prevent damage to the rectifier during press-in, the pressing force should be applied only on the shoulder ring of the rectifier case.
5. The pressing force should be applied evenly about the shoulder ring to avoid tilting or canting of the rectifier case in the hole during the press-in operation. Also, the use of a thermal lubricant such as D.C. 340 will be of considerable aid.

For more information see: Mounting Techniques for Metal Packaged Power Semiconductors, AN-599.



HEAT SINK MOUNTING



THIN-CHASSIS MOUNTING

MOTOROLA

MBR6020 MBR6035 MBR6045 MBR6045H, H1

Advance Information

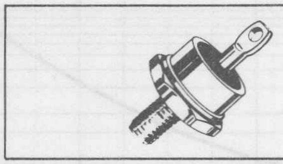
SWITCHMODE POWER RECTIFIERS

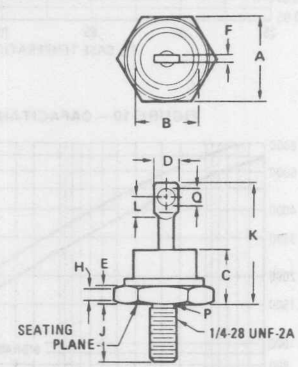
. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free-wheeling diodes, and polarity-protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- TX Version Available
- Low Power Loss/ High Efficiency
- High Surge Capacity

SCHOTTKY BARRIER RECTIFIERS

60 AMPERES
20 to 45 VOLTS



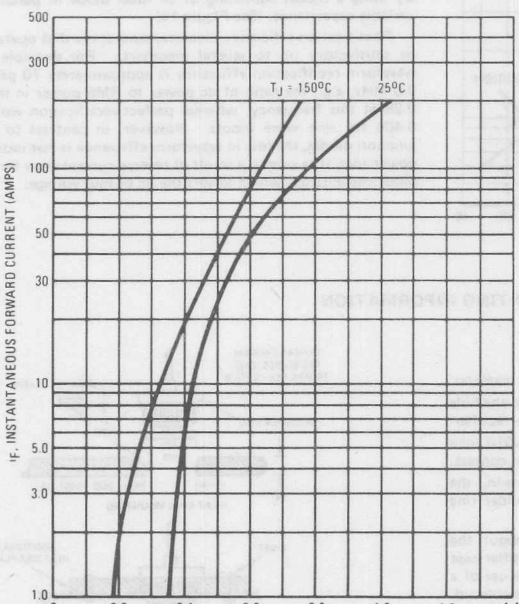


DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.86	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

FIGURE 1 – TYPICAL FORWARD VOLTAGE



MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion-resistant and terminal lead is readily solderable.

POLARITY: Cathode to case

MOUNTING POSITIONS: Any

STUD TORQUE: 25 in. lb. max

This is advance information on a new introduction and specifications are subject to change without notice.

MAXIMUM RATINGS

Rating	Symbol	MBR6020	MBR6035	MBR6045 MBR6045H, H1	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	35	45	Volts
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20 kHz)	I_{FRM}	120 $T_C = 90°C$	120 $T_C = 90°C$	120 $T_C = 90°C$	Amp
Average Rectified Forward Current (Rated V_R)	I_O	50 $T_C = 90°C$	50 $T_C = 90°C$	50 $T_C = 90°C$	Amp
Case Temperature (Rated V_R)	T_C	140	140	140	°C
Non-repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	←	800	→	Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +150	-65 to +150	-65 to +150	°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	175	175	175	°C
Voltage Rate of Change (Rated V_R)	dv/dt	1000	1000	1000	v/μs

THERMAL CHARACTERISTICS

Characteristic	Symbol	MBR6020	MBR6035	MBR6045 MBR6045H, H1	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	←	1.0	→	°C/W

ELECTRICAL CHARACTERISTICS (T_C = 25°C unless otherwise noted)

Characteristic	Symbol	MBR6020	MBR6035	MBR6045 MBR6045H, H1	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 157 Amp, T_C = 70°C) (i_F = 157 Amp, T_C = 125°C)	v_F	— 0.80	— 0.80	— 0.80	Volts
Maximum Instantaneous Reverse Current (1) (Rated dc Voltage, T_C = 125°C)	i_R	75	100	150	mA
Capacitance (V_R = 1.0 Vdc, 100 kHz ≤ f ≤ 1.0 MHz)	C_t	4000	4000	4000	pF

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

FIGURE 2 — CURRENT DERATING
(MBR6020, MBR6035, MBR6045, MBR6045H, H1)

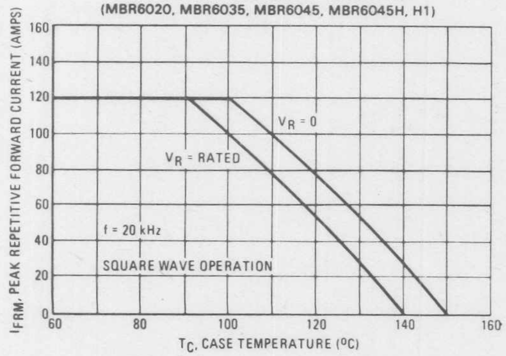
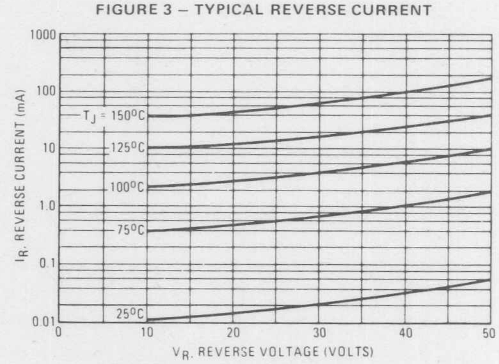
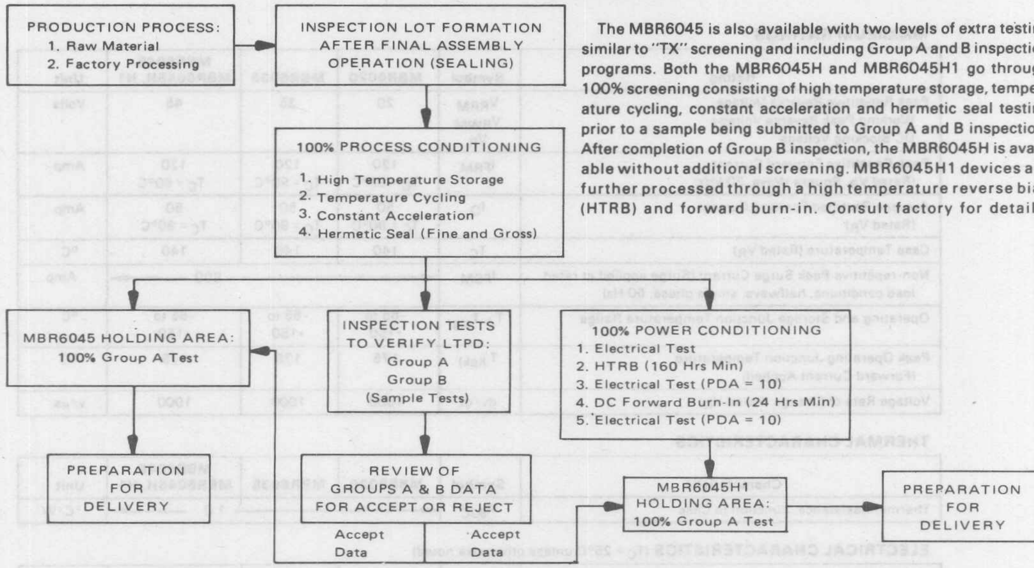


FIGURE 3 – TYPICAL REVERSE CURRENT



NOTE 1 — HI-REL PROGRAM OPTIONS

The MBR6045 is also available with two levels of extra testing similar to "TX" screening and including Group A and B inspection programs. Both the MBR6045H and MBR6045H1 go through 100% screening consisting of high temperature storage, temperature cycling, constant acceleration and hermetic seal testing prior to a sample being submitted to Group A and B inspection. After completion of Group B inspection, the MBR6045H is available without additional screening. MBR6045H1 devices are further processed through a high temperature reverse bias (HTRB) and forward burn-in. Consult factory for details.



MBR7520 MBR7530 MBR7535 MBR7540 MBR7545 MBR7545H, H1

MOTOROLA

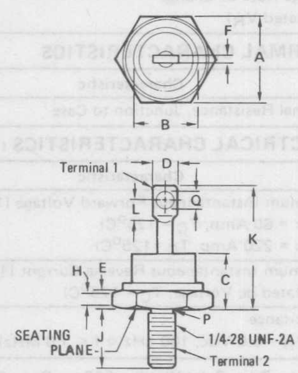
SCHOTTKY BARRIER RECTIFIERS

75 AMPERES
20 to 45 VOLTS

SWITCHMODE POWER RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State-of-the-art geometry features epitaxial construction with oxide passivation and metal overlap contact. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free-wheeling diodes, and polarity-protection diodes.

- Extremely Low v_F
- Low Stored Charge, Majority Carrier Conduction
- TX Version Available
- Low Power Loss/High Efficiency
- High Surge Capacity

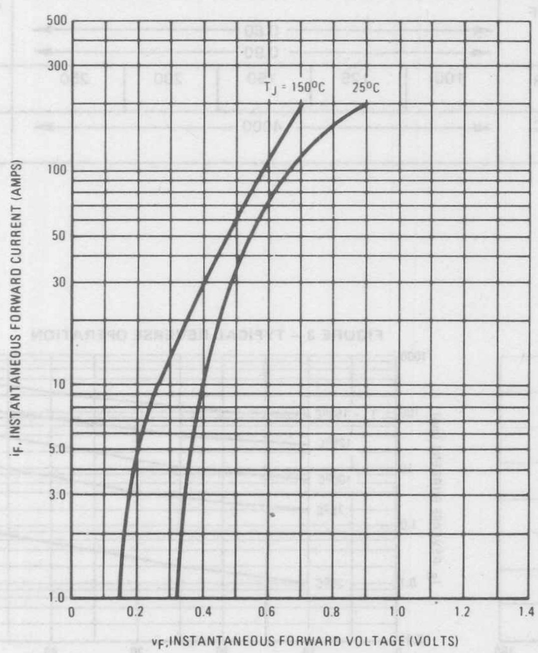


DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.86	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

FIGURE 1 – TYPICAL FORWARD VOLTAGE



MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion-resistant and terminal lead is readily solderable.

POLARITY: Cathode to case

MOUNTING POSITIONS: Any

STUD TORQUE: 25 in. lb. max

MAXIMUM RATINGS

Rating	Symbol	MBR7520	MBR7530	MBR7535	MBR7540	MBR7545H,H1 MBR7545	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	20	30	35	40	45	Volts
Peak Repetitive Forward Current (Rated V_R, Square Wave, 20 kHz)	I_{FRM}			150 $T_C = 90^oC$			Amp
Average Rectified Forward Current (Rated V_R)	I_O			70 $T_C = 90^oC$			Amp
Non-repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}			1000			Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}			-65 to +150			^oC
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$			175			^oC
Voltage Rate of Change (Rated V_R)	dv/dt			1000			v/μs

THERMAL CHARACTERISTICS

Characteristic	Symbol	MBR7520	MBR7530	MBR7535	MBR7540	MBR7545H,H1 MBR7545	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$			0.8			$^oC/W$

ELECTRICAL CHARACTERISTICS ($T_C = 25^oC$ unless otherwise noted)

Characteristic	Symbol	MBR7520	MBR7530	MBR7535	MBR7540	MBR7545H,H1 MBR7545	Unit
Maximum Instantaneous Forward Voltage (1) (i_F = 60 Amp, $T_C = 125^oC$) (i_F = 220 Amp, $T_C = 125^oC$)	v_F			 0.60 0.90			Volts
Maximum Instantaneous Reverse Current (1) (Rated dc Voltage, $T_C = 125^oC$)	i_R	100	125	150	200	250	mA
Capacitance (V_R = 5.0 Vdc, 100 kHz ≤ f ≤ 1.0 MHz)	C_t			4000			pF

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

FIGURE 2 – CURRENT DERATING

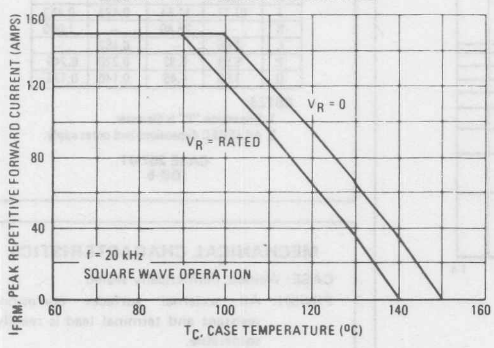
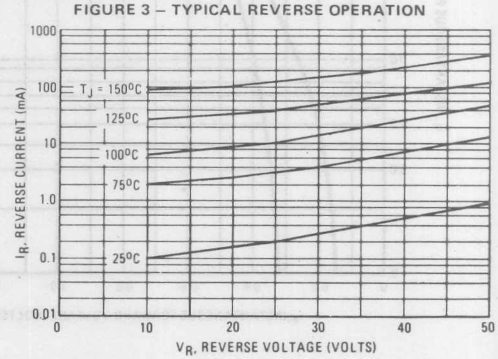


FIGURE 3 – TYPICAL REVERSE OPERATION



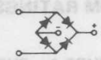
MOTOROLA

MDA100A series

MINIATURE INTEGRAL DIODE ASSEMBLIES

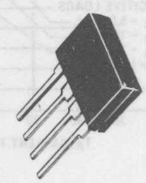
. . . with silicon rectifier chips interconnected and encapsulated into voidless rectifier bridge circuits.

- High Resistance to Shock and Vibration
- High Dielectric Strength
- Built-In Printed Circuit Board Stand-Offs
- UL Recognized



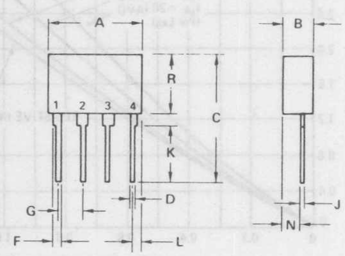
SINGLE-PHASE FULL-WAVE BRIDGE

1.0 AMPERE
50-1000 VOLTS



MAXIMUM RATINGS

Rating (Per Diode)	Symbol	MDA100A	MDA101A	MDA102A	MDA104A	MDA106A	MDA108A	MDA110A	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
DC Output Voltage Resistive Load	Vdc	32	64	127	255	382	510	640	Volts
Capacitive Load	Vdc	50	100	200	400	600	800	1000	Volts
Sine Wave RMS Input Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (single phase bridge operation, resistive load, 60 Hz, T_A = 75°C)	I_O	← 1.0 →							Amp
Non-Repetitive Peak Surge Current (Preceded and followed by rated current and voltage, T_A = 75°C)	I_{FSM}	← 30 (for 1 cycle) →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -55 to +150 →							°C



STYLE 1:
TERM 1. POS
2. AC
3. AC
4. NEG

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) (i_F = 1.57 Amp, T_J = 25°C)	v_F	1.15	1.3	Volts
Reverse Current (Per Diode) (Rated V_R, T_A = 25°C)	I_R	–	10	μA

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	14.99	15.49	0.590	0.610
B	4.57	5.08	0.180	0.200
C	–	20.57	–	0.810
D	0.76	1.02	0.030	0.040
F	1.02	1.27	0.040	0.050
G	3.68	3.94	0.145	0.155
J	0.56	0.71	0.022	0.028
K	–	9.02	–	0.355
L	1.78	2.03	0.070	0.080
N	2.54	2.79	0.100	0.110
R	9.40	10.03	0.370	0.395

CASE 312-02

MECHANICAL CHARACTERISTICS

CASE: Transfer Molded Plastic

POLARITY: Terminal-designation on case
(+) for DC output
(-) for DC output
(AC) for AC input

MOUNTING POSITION: Any

WEIGHT: 1.8 grams (approx)

TERMINALS: Readily solderable connections, corrosion resistant.

MAXIMUM RATINGS, BRIDGE OPERATION

FIGURE 1 – CURRENT DERATING

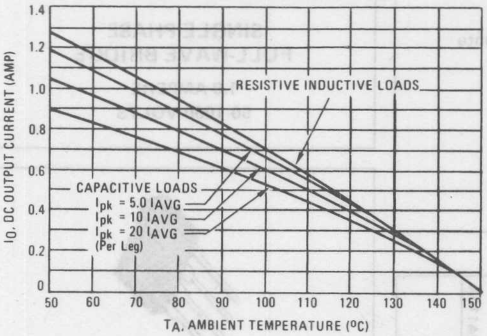


FIGURE 2 – POWER DISSIPATION

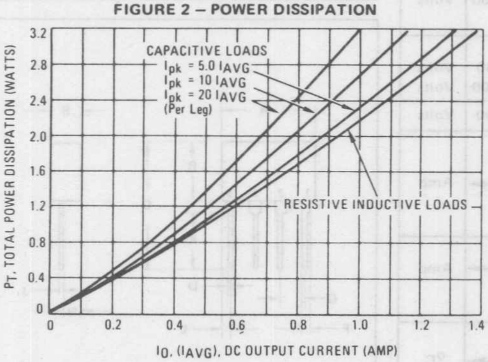
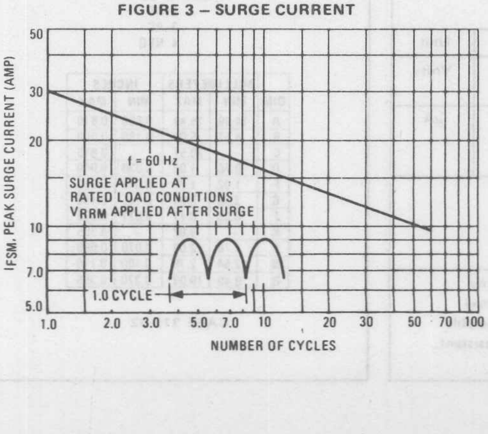


FIGURE 3 – SURGE CURRENT



SINGLE DIODE CHARACTERISTICS

FIGURE 4 – MAXIMUM FORWARD VOLTAGE

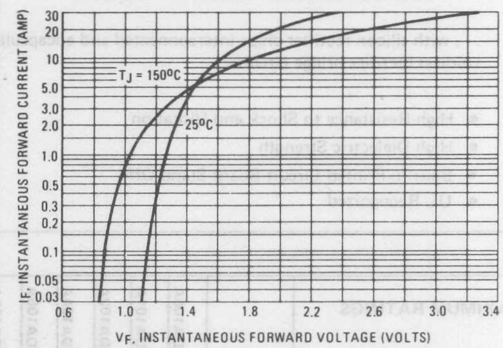


FIGURE 5 – FORWARD RECOVERY TIME

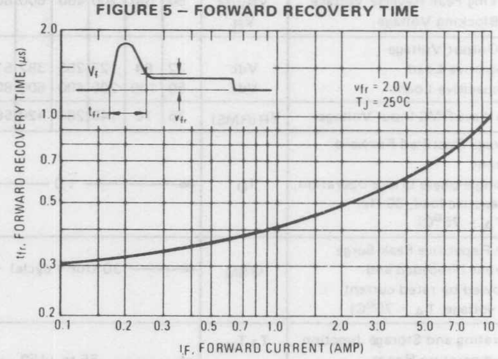
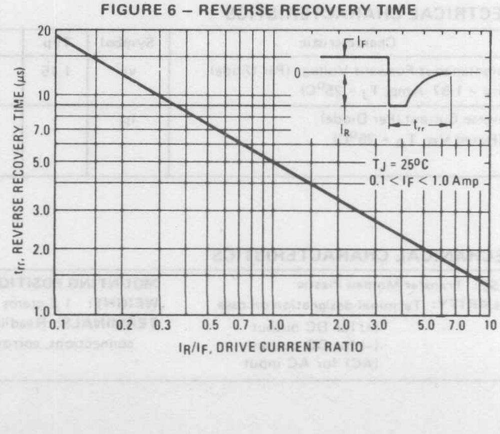


FIGURE 6 – REVERSE RECOVERY TIME



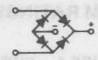
MOTOROLA

MDA200 series

MINIATURE INTEGRAL DIODE ASSEMBLIES

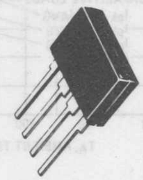
. . . with silicon rectifier chips interconnected and encapsulated into voidless rectifier bridge circuits.

- High Resistance to Shock and Vibration
- High Dielectric Strength
- Built-In Printed Circuit Board Stand-Offs
- UL Recognized

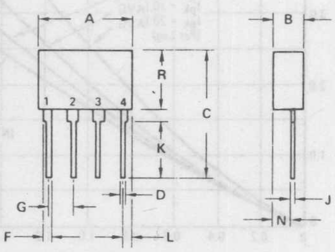


SINGLE-PHASE
FULL-WAVE BRIDGE

2.0 AMPERES
50-1000 VOLTS



MAXIMUM RATINGS Rating (Per Diode)	Symbol	MDA200	MDA201	MDA202	MDA204	MDA206	MDA208	MDA210	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
DC Output Voltage Resistive Load	Vdc	32	64	127	255	382	510	640	Volts
Capacitive Load	Vdc	50	100	200	400	600	800	1000	Volts
Sine Wave RMS Input Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (single phase bridge operation, resistive load, 60 Hz, T_A - 55°C)	I_O	← 2.0 →							Amp
Non-Repetitive Peak Surge Current (Preceded and followed by rated current and voltage, T_A = 55°C)	I_{FSM}	← 60 (for 1 cycle) →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -55 to +165 →							°C



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	14.99	15.49	0.590	0.610
B	4.57	5.08	0.180	0.200
C	–	20.57	–	0.810
D	0.76	1.02	0.030	0.040
F	1.02	1.27	0.040	0.050
G	3.68	3.94	0.145	0.155
J	0.56	0.71	0.022	0.028
K	–	9.02	–	0.355
L	1.78	2.03	0.070	0.080
N	2.54	2.79	0.100	0.110
R	9.40	10.03	0.370	0.395

CASE 312-02

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) (i_F = 3.14 Amp, T_J = 25°C)	v_F	1.0	1.1	Volts
Reverse Current (Per Diode) (Rated V_R, T_A = 25°C)	I_R	–	10	µA

MECHANICAL CHARACTERISTICS

CASE: Transfer Molded Plastic

POLARITY: Terminal designation on case
(+) for DC output
(–) for DC output
(AC) for AC input

MOUNTING POSITION: Any

WEIGHT: 1.8 grams (approx)

TERMINALS: Readily solderable connections, corrosion resistant.

MAXIMUM RATINGS, BRIDGE OPERATION

FIGURE 1 – CURRENT DERATING

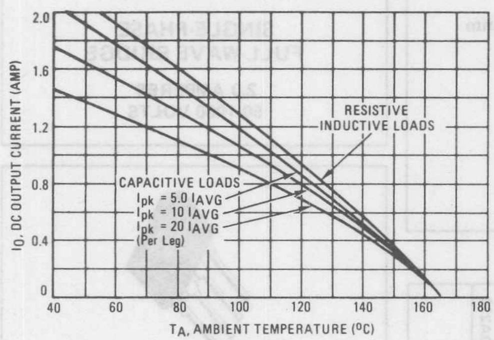


FIGURE 2 – POWER DISSIPATION

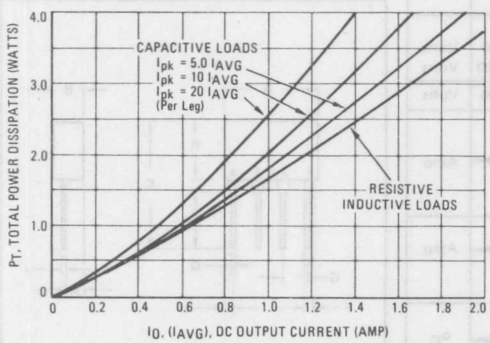
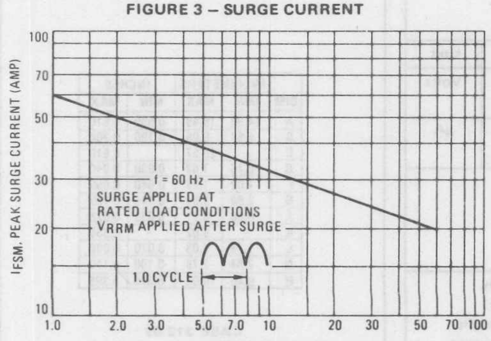


FIGURE 3 – SURGE CURRENT



SINGLE DIODE CHARACTERISTICS

FIGURE 4 – MAXIMUM FORWARD VOLTAGE

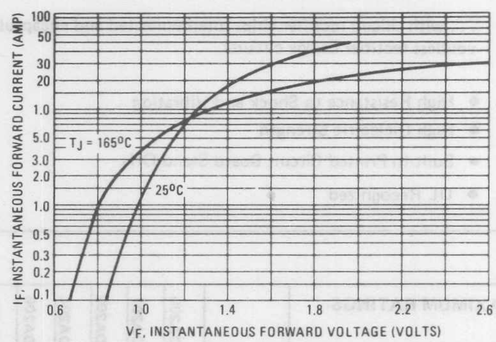


FIGURE 5 – FORWARD RECOVERY TIME

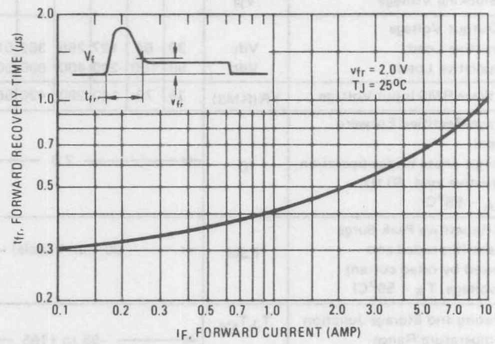
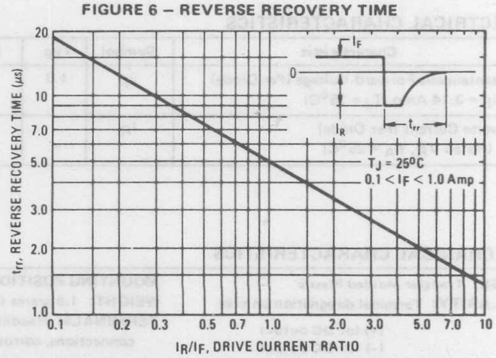


FIGURE 6 – REVERSE RECOVERY TIME



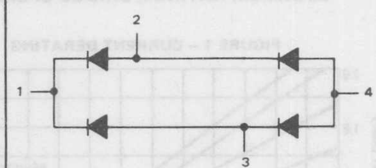
MOTOROLA

MDA220

SECONDARY TRANSIENT PROTECTOR

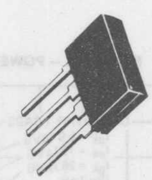
. . . designed for use in a telephone subscriber loop interface circuit. See Figure 9.

- High Resistance to Shock and Vibration
- High Dielectric Strength
- Built-In Printed Circuit Board Stand-Offs



TELEPHONE SECONDARY TRANSIENT PROTECTOR

2.0 AMPERES
100 VOLTS



MAXIMUM RATINGS

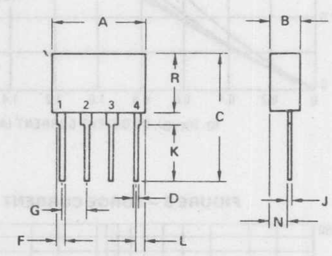
Rating (Per Diode)	Symbol	Value	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	100	Volts
Average Rectified Forward Current (Single phase bridge operation, resistive load, 60 Hz, $T_A = 55^oC$)	I_O	2.0	Amp
Non-Repetitive Peak Surge Current (Preceded and followed by rated current and voltage, $T_A = 55^oC$)	I_{FSM}	60 (for 1 cycle)	Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−55 to +165	^oC
Non-Repetitive Transient Protection (Fig. 7)	–	50	A/μs

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) ($i_F = 3.14$ Amp, $T_J = 25^oC$)	v_F	1.0	1.1	Volts
Reverse Current (Per Diode) (Rated V_R, $T_A = 25^oC$)	I_R	–	10	μA

MECHANICAL CHARACTERISTICS

CASE . . . . Transfer Molded Plastic
POLARITY . . . . Terminal designation on case
MOUNTING POSITION . . . . Any
WEIGHT . . . . 1.8 grams (approx)
TERMINALS . . . . Readily solderable connections, corrosion resistant



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	14.99	15.49	0.590	0.610
B	4.57	5.08	0.180	0.200
C	–	20.57	–	0.810
D	0.76	1.02	0.030	0.040
F	1.02	1.27	0.040	0.050
G	3.68	3.94	0.145	0.155
J	0.56	0.71	0.022	0.028
K	–	9.02	–	0.355
L	1.78	2.03	0.070	0.080
N	2.54	2.79	0.100	0.110
R	9.40	10.03	0.370	0.395

CASE 312-02

MAXIMUM RATINGS, BRIDGE OPERATION

FIGURE 1 – CURRENT DERATING

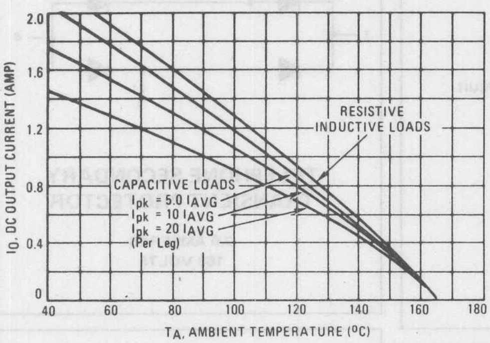


FIGURE 2 – POWER DISSIPATION

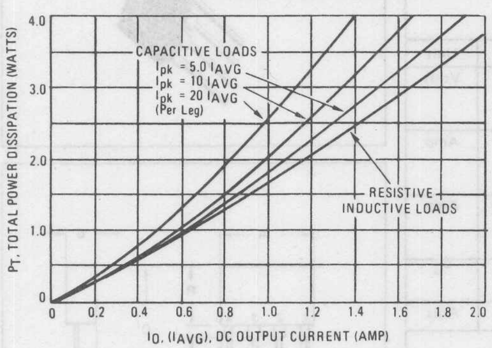
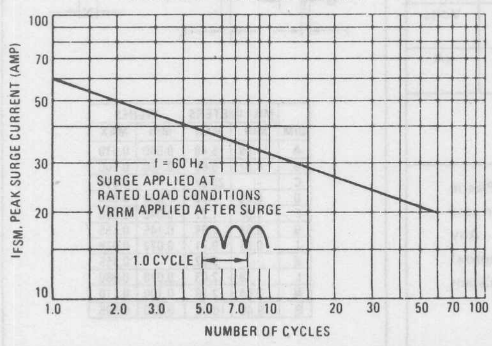


FIGURE 3 – SURGE CURRENT



SINGLE DIODE CHARACTERISTICS

FIGURE 4 – MAXIMUM FORWARD VOLTAGE

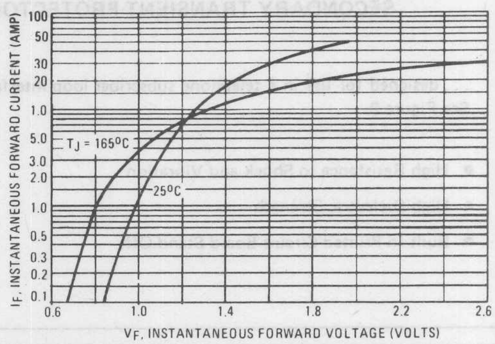


FIGURE 5 – FORWARD RECOVERY TIME

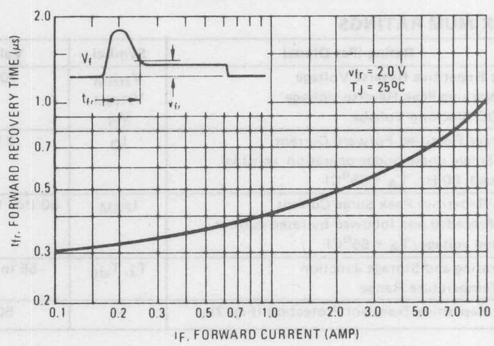
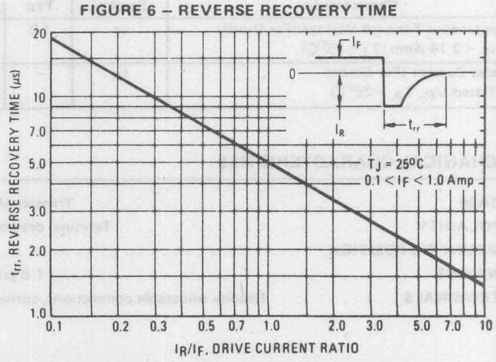


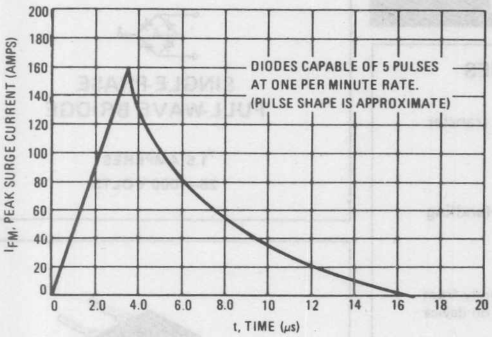
FIGURE 6 – REVERSE RECOVERY TIME



TRANSIENT CAPABILITIES AND CHARACTERISTICS

FIGURE 7 – NON-REPETITIVE SURGE CURRENT

a.



b.

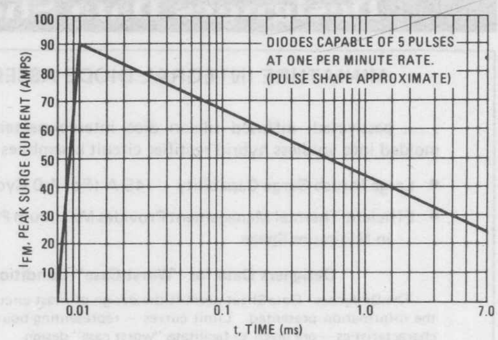
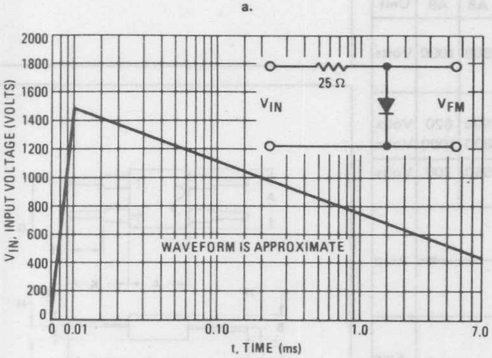


FIGURE 8 – FORWARD VOLTAGE versus TIME

a.



b.

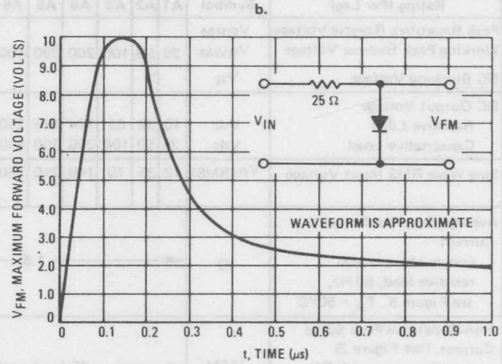
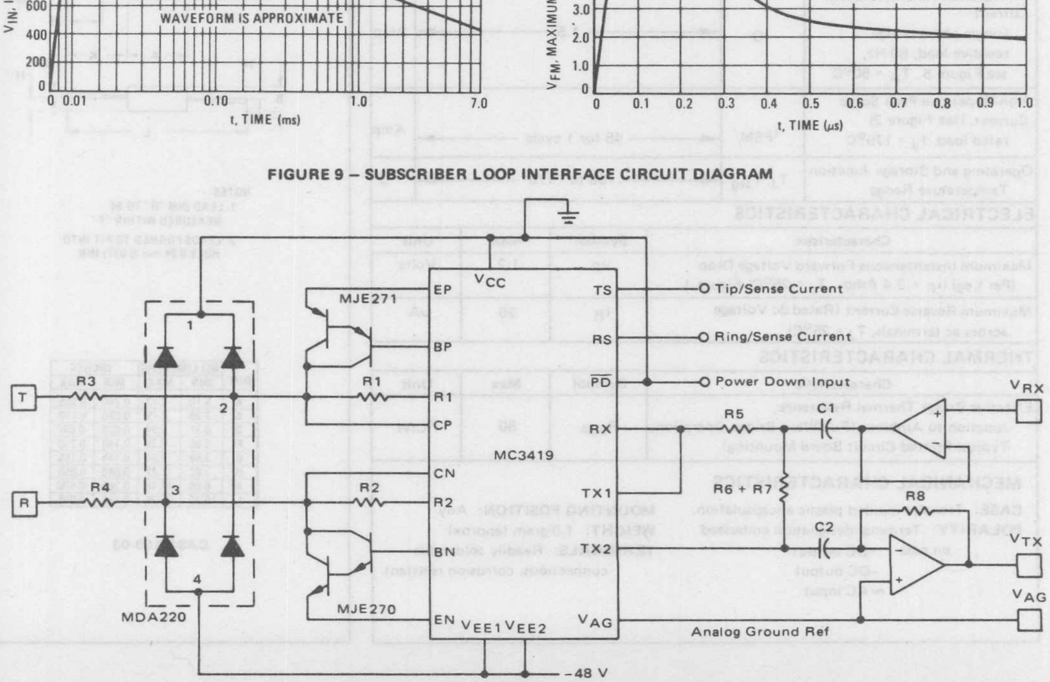
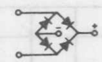


FIGURE 9 – SUBSCRIBER LOOP INTERFACE CIRCUIT DIAGRAM



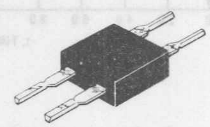
MOTOROLA

MDA920A1 thru MDA920A9



SINGLE-PHASE FULL-WAVE BRIDGE

1.5 AMPERES
25–1000 VOLTS



Designers Data Sheet

MINIATURE INTEGRAL DIODE ASSEMBLIES

. . . passivated, diffused-silicon dice interconnected and transfer molded into voidless hybrid rectifier circuit assemblies.

- Large Inrush Surge Capability – 45 A (For 1.0 Cycle)
- Efficient Thermal Management Provides Maximum Power Handling in Minimum Space

Designers Data for "Worst Case" Conditions

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

MAXIMUM RATINGS

Rating (Per Leg)	Symbol	A1	A2	A3	A4	A5	A6	A7	A8	A9	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	25	50	100	200	300	400	600	800	1000	Volts
DC Output Voltage Resistive Load Capacitative Load	 Vdc Vdc	 15 25	 30 50	 62 100	 124 200	 185 300	 250 400	 380 600	 500 800	 620 1000	 Volts Volts
Sine Wave RMS Input Voltage	$V_{R(RMS)}$	18	35	70	140	210	280	420	560	700	Volts
Average Rectified Forward Current (single phase bridge resistive load, 60 Hz, see Figure 6, $T_A = 50^oC$	I_O	← 1.5 →									Amp
Non-Repetitive Peak Surge Current, (see Figure 2) rated load, $T_J = 175^oC$	I_{FSM}	← 45 for 1 cycle →									Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -55 to +175 →									^oC

ELECTRICAL CHARACTERISTICS

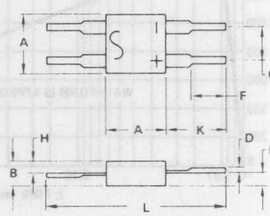
Characteristic	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage Drop (Per Leg) ($i_F = 2.4$ Amp, $T_J = 25^oC$) Figure 1	v_F	1.2	Volts
Maximum Reverse Current (Rated dc Voltage across ac terminals, $T_J = 25^oC$)	I_R	20	μA

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Effective Bridge Thermal Resistance, Junction to Ambient (Full-Wave Bridge Operation, Typical Printed Circuit Board Mounting)	$R_{\theta JA}$	50	$^oC/W$

MECHANICAL CHARACTERISTICS

CASE: Transfer-molded plastic encapsulation.
POLARITY: Terminal-designation embossed on case +DC output
-DC output
∼AC input
MOUNTING POSITION: Any
WEIGHT: 1.0 gram (approx)
TERMINALS: Readily solderable connections, corrosion resistant.



NOTES:
1. LEAD DIM "D" TO BE MEASURED WITHIN "F"
2. LEADS FORMED TO FIT INTO HOLE 0.94 mm (0.037) MIN.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	6.10	6.73	0.240	0.265
B	2.29	2.79	0.090	0.110
D	0.51	0.94	0.020	0.037
F	3.56	6.35	0.140	0.250
G	3.68	3.94	0.145	0.155
H	1.02	1.27	0.040	0.050
K	6.60	10.16	0.260	0.400
L	19.30	27.05	0.760	1.065

CASE 109-03

FIGURE 1 – FORWARD VOLTAGE (PER LEG)

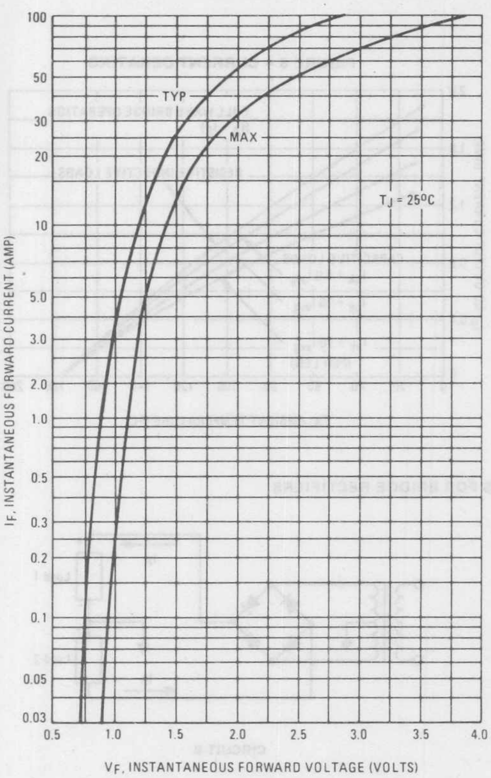


FIGURE 2 – MAXIMUM SURGE CAPABILITY

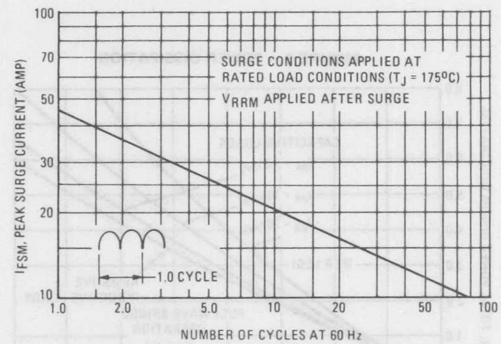


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

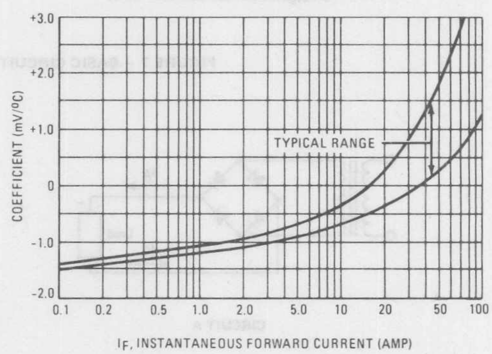


FIGURE 4 – TYPICAL THERMAL RESPONSE

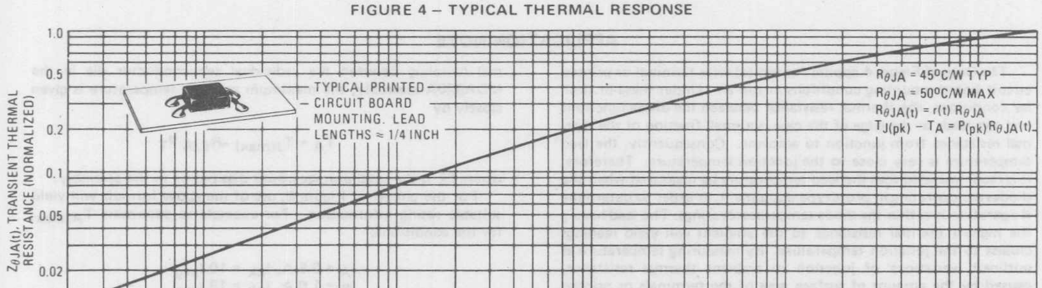


FIGURE 5 – POWER DISSIPATION

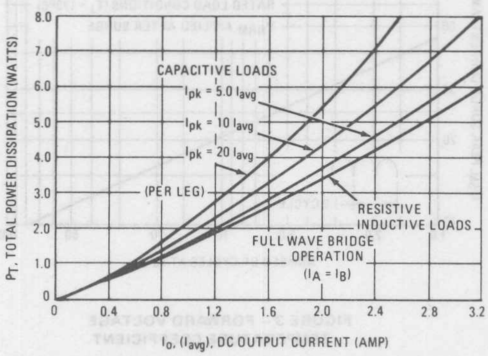


FIGURE 6 – CURRENT DERATING

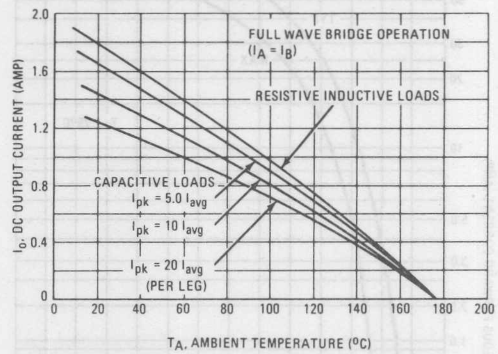
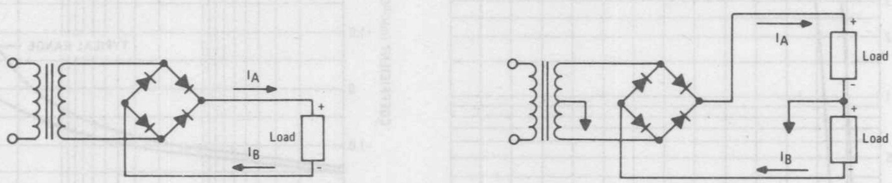


FIGURE 7 – BASIC CIRCUIT USES FOR BRIDGE RECTIFIERS



CIRCUIT A CIRCUIT B

APPLICATION NOTE

The Data of Figure 4 applies for typical wire terminal or printed circuit board mounting conditions in still air. Under these or similar conditions, the thermal resistance between the diode junctions and the leads at the edge of the case is a small fraction of the thermal resistance from junction to ambient. Consequently, the lead temperature is very close to the junction temperature. Therefore, it is recommended that the lead temperature be measured when the diodes are operating in prototype equipment, in order to determine if operation is within the diode temperature ratings. The lead having the highest thermal resistance to the ambient will yield readings closest to the junction temperature. By measuring temperature as outlined, variations of junction to ambient thermal resistance, caused by the amount of surface area of the terminals or printed circuit board and the degree of air convection, as well as proximity of other heat sources cease to be important design considerations.

Bridge rectifiers are used in two basic circuit configurations as shown by circuits A and B of Figure 7. The current derating data of Figure 6 applies to the standard bridge circuit (A), where $I_A = I_B$. The derating data considers the thermal response of the junction and is based upon the criteria that the junction temperature must not exceed rated $T_{J(max)}$ when peak reverse voltage is applied. However, because of the slow thermal response and the close thermal coupling between the individual semiconductor die in the MDA920A assembly, the maximum ambient temperature is given closely by

$$T_A = T_{J(max)} - R_{\theta JA} P_T$$

where P_T is the total average power dissipation in the assembly.

For the circuit of Figure B, use of the above formula will yield suitable rating information. For example to determine $T_{A(max)}$ for the conditions:

$$I_A = 0.5\text{ A},\ I_{pk} = 10\ I_{avg}$$
$$I_B = 1.0\text{ A},\ I_{pk} = 18\ I_{avg}$$

From Figure 5: For I_A, read $P_{TA} \approx 0.8$ W
For I_B, read $P_{TB} \approx 2.2$ W

$$P_T = (P_{TA} + P_{TB}) \div 2 = 1.5\text{ W}$$

(Division by 2 is necessary as data from Figure 5 is for full-wave bridge operation.) $\therefore T_{A(max)} = 175^\circ - (50)(1.5) = 100^\circ$C.

FIGURE 8 – FORWARD RECOVERY TIME

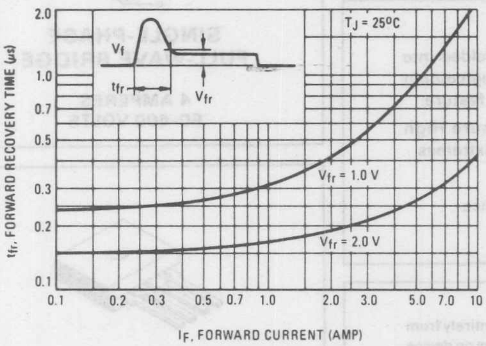


FIGURE 9 – REVERSE RECOVERY TIME

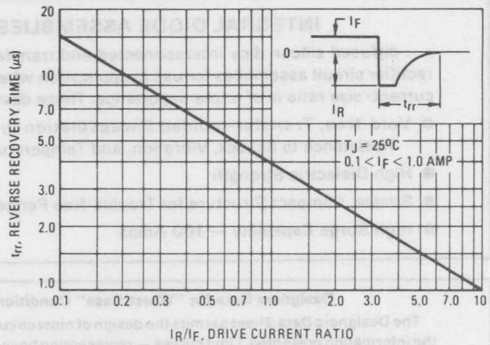


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY

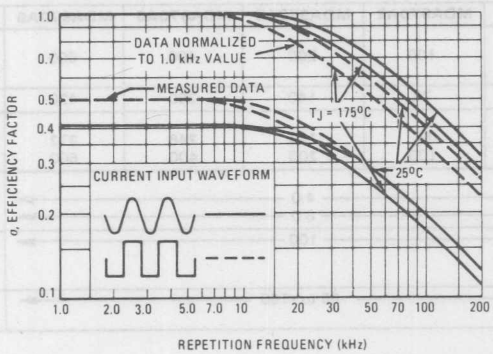


FIGURE 11 – CAPACITANCE

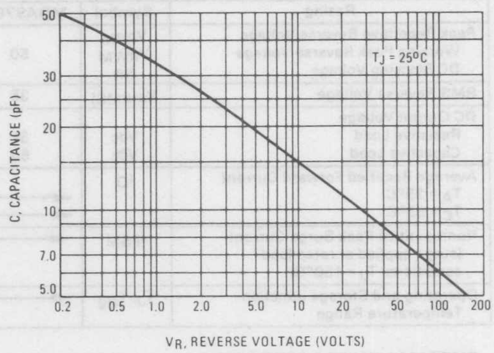
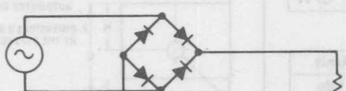


FIGURE 12 – SINGLE-PHASE FULL-WAVE BRIDGE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{(dc)}}{P_{(rms)}} = \frac{\dfrac{V^2{}_{o(dc)}}{R_L}}{\dfrac{V^2{}_{o(rms)}}{R_L}} \cdot 100\% = \frac{V^2{}_{o(dc)}}{V^2{}_{o(ac)} + V^2{}_{o(dc)}} \cdot 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assumed lossless, the maximum theoretical efficiency factor becomes:

RECTIFIER EFFICIENCY NOTE

$$\sigma_{(sine)} = \frac{\dfrac{4V^2{}_m}{\pi^2 R_L}}{\dfrac{V^2{}_m}{2R_L}} \cdot 100\% = \frac{8}{\pi^2} \cdot 100\% = 81.2\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\dfrac{V^2{}_m}{R_L}}{\dfrac{V^2{}_m}{R_L}} \cdot 100\% = 100\% \quad (3)$$

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 10.

It should be emphasized that Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_o with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

MOTOROLA

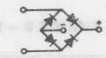
MDA970A1 thru MDA970A6

Designers Data Sheet

INTEGRAL DIODE ASSEMBLIES

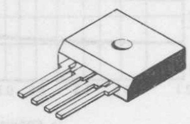
. . . diffused silicon dice interconnected and transfer molded into rectifier circuit assemblies for use in application where high output current/size ratio is of prime importance. These devices feature:

- Void-free, Transfer-molded Encapsulation to Assure High Resistance to Schock, Vibration, and Temperature Extremes
- High Dielectric Strength
- Simple, Compact Structure for Trouble-free Performance
- High Surge Capability — 100 Amps



SINGLE-PHASE FULL-WAVE BRIDGE

4 AMPERES
50-600 VOLTS



Designers Data for "Worst Case" Conditions

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

MAXIMUM RATINGS ($T_A = 25°C$ unless otherwise noted)

Rating	Symbol	MDA970A1	MDA970A2	MDA970A3	MDA970A5	MDA970A6	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	Volts
DC Output Voltage Resistive Load Capactive Load	 Vdc Vdc	 31 50	 62 100	 124 200	 248 400	 372 600	Volts
Average Rectified Forward Current $T_A = 25°C$ $T_C = 55°C$	I_O	 4.0 8.0					Amp
Nonrepetitive Peak Surge Current (surge applied at rated load conditions, $T_J = 150°C$)	I_{FSM}	100					Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +150					°C

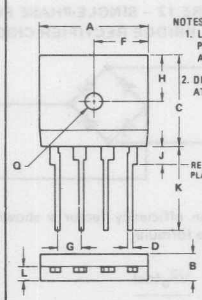
THERMAL CHARACTERISTICS

Characteristics		Symbol	Max (Per Die)	Unit
Thermal Resistance, Junction to Case	Each Die	$R_{\theta JC}$	10	°C/W
	Effective Bridge	$R_{\theta(EFF)}$	7.75	°C/W

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Max	Unit
Instaneous Forward Voltage (Per Diode) ($i_F = 6.28$ Amp, $T_J = 25°C$) ($i_F = 6.28$ Amp, $T_J = 150°C$)	v_F	— — —	 1.1 1.0	Vdc
Reverse Current (Rated V_{RM} applied to ac terminals, + and - terminals open, $T_A = 25°C$)	I_R	—	1.0	mA

CASE: Transfer-molded plastic encapsulation.
FINISH: All external surfaces are corrosion-resistant. Leads are readily solderable.
POLARITY: Embossed symbols
AC input = ~ DC output = + DC output = -
MOUNTING POSITION: Any
WEIGHT (Approximately): 7.5 Grams
MOUNTING TORQUE: 5 in.-lb. Max



NOTES:
1. LEADS ARE SQUARE AND OFFSET ON PACKAGE (DIM L) TO ALLOW FOR AUTOMATED EQUIPMENT LOADING.
2. DIMENSIONS G & L SHALL BE MEASURED AT THE REFERENCE PLANE.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	22.35	23.37	0.880	0.920
B	6.35	7.37	0.250	0.290
C	18.54	19.56	0.730	0.770
D	0.89	1.14	0.035	0.045
F	11.18	11.68	0.440	0.460
G	4.57	5.59	0.180	0.220
H	8.89	9.91	0.350	0.390
J	2.79	3.81	0.110	0.150
K	14.81	–	0.575	–
L	3.18	3.43	0.125	0.135
Q	3.56	4.06	0.140	0.160

CASE 117A-02

FIGURE 1 – FORWARD VOLTAGE

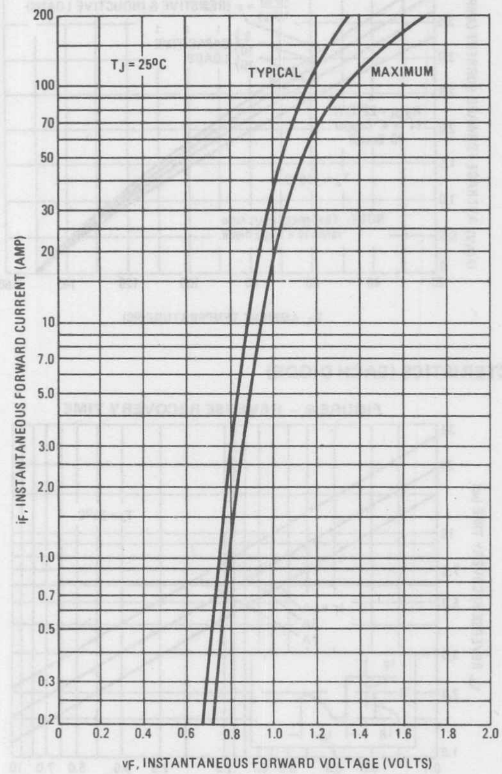


FIGURE 2 – MAXIMUM SURGE CAPABILITY

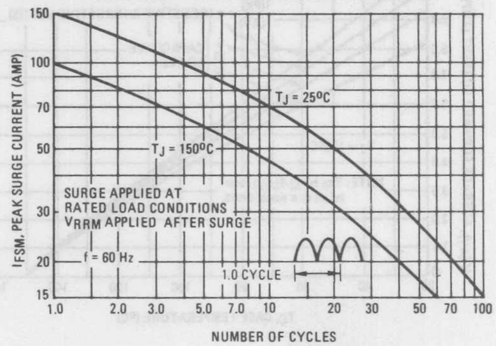


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

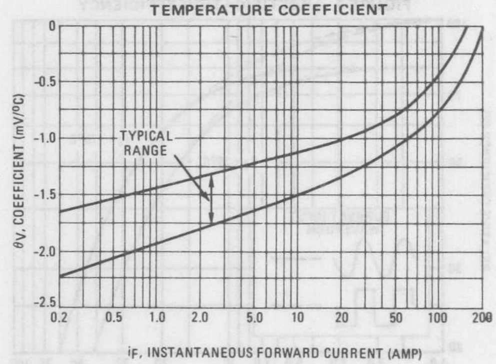
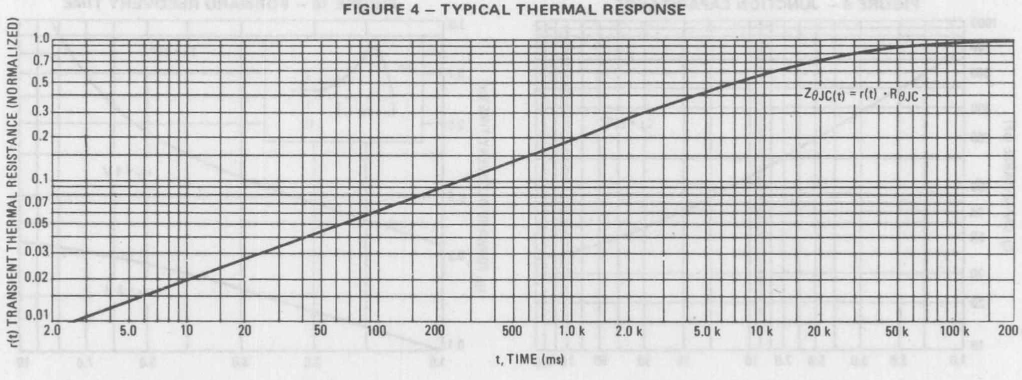


FIGURE 4 – TYPICAL THERMAL RESPONSE



MAXIMUM CURRENT RATINGS, BRIDGE OPERATION

FIGURE 5 – CASE TEMPERATURE DERATING

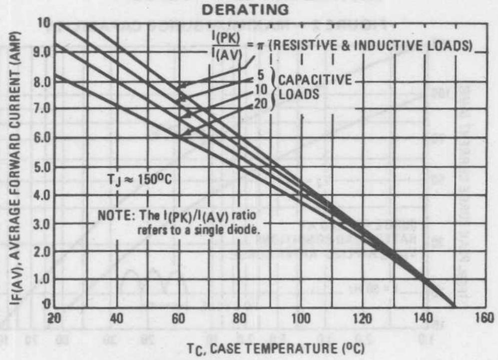
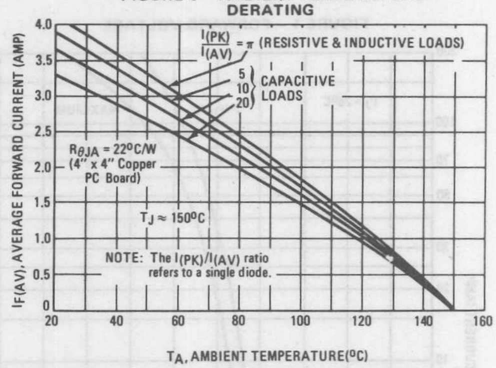


FIGURE 6 – AMBIENT TEMPERATURE DERATING



TYPICAL DYNAMIC CHARACTERISTICS (EACH DIODE)

FIGURE 7 – RECTIFICATION EFFICIENCY

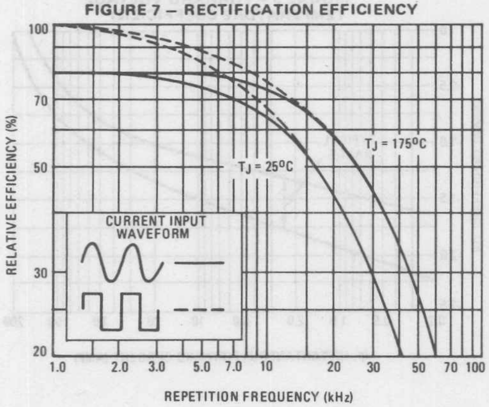


FIGURE 8 – REVERSE RECOVERY TIME

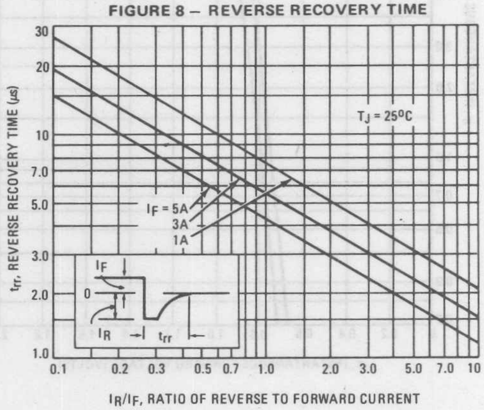


FIGURE 9 – JUNCTION CAPACITANCE

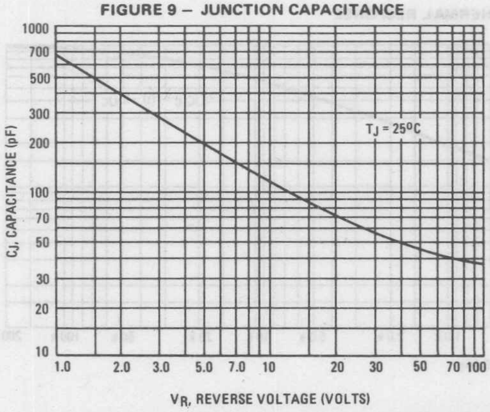


FIGURE 10 – FORWARD RECOVERY TIME

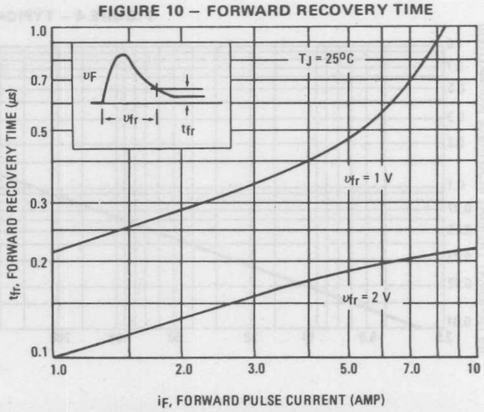


FIGURE 11 — POWER DISSIPATION

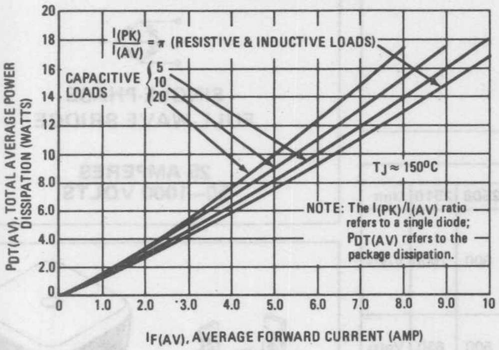
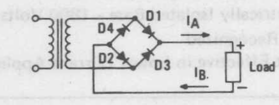
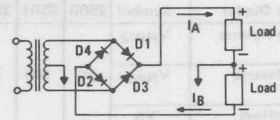


FIGURE 12 — BASIC CIRCUIT USES FOR BRIDGE RECTIFIERS



CIRCUIT A



CIRCUIT B

NOTE 1: THERMAL COUPLING AND EFFECTIVE THERMAL RESISTANCE

In multiple chip devices where there is coupling of heat between die, the junction temperature can be calculated as follows:

(1) $\Delta T_{J1} = R_{\theta 1} P_{D1} + R_{\theta 2} K_{\theta 2} P_{D2} + R_{\theta 3} K_{\theta 3} P_{D3} + R_{\theta 4} K_{\theta 4} P_{D4}$

Where ΔT_{J1} is the change in junction temperature of diode 1
$R_{\theta 1}$ thru 4 is the thermal resistance of diodes 1 through 4
P_{D1} thru 4 is the power dissipated in diodes 1 through 4
$K_{\theta 2}$ thru 4 is the thermal coupling between diode 1 and diodes 2 through 4.

An effective package thermal resistance can be defined as follows:

(2) $R_{\theta(EFF)} = \Delta T_{J1}/P_{DT}$

where: P_{DT} is the total package power dissipation.

Assuming equal thermal resistance for each die, equation (1) simplifies to

(3) $\Delta T_{J1} = R_{\theta 1} (P_{D1} + K_{\theta 2} P_{D2} + K_{\theta 3} P_{D3} + K_{\theta 4} P_{D4})$

For the conditions where $P_{D1} = P_{D2} = P_{D3} = P_{D4}$, $P_{DT} = 4 P_D$ equation (3) can be further simplified and by substituting into equation (2) results in

(4) $R_{\theta(EFF)} = R_{\theta 1}(1 + K_{\theta 2} + K_{\theta 3} + K_{\theta 4})/4$

For this rectifier assembly, thermal coupling between opposite diodes is 65% and between adjacent diodes is 72.5% when the case temperature is used as a reference. When the ambient temperature is used as the reference, the coupling is a function of the mounting conditions and is essentially the same for opposite and adjacent diodes.

The effective bridge thermal resistance, junction to ambient, is (from equation 4).

(5) $R_{\theta(EFF)JA} = R_{\theta JA}(1 + 3K_{\theta(AV)JA})/4$

Where: $K_{\theta(AV)JA} \approx (K_{\theta(AV)JC} R_{\theta JC} + R_{\theta CA})/R_{\theta JA}$ and $K_{\theta(AV)JC}$ is approximately 70%. $R_{\theta CA}$ is the case to ambient thermal resistance.

NOTE 2: SPLIT LOAD DERATING INFORMATION

Bridge rectifiers are used in two basic configurations as shown by circuits A and B of Figure 12. The current derating data of Figures 5 and 6 apply to the standard bridge circuit (A) where $I_A = I_B$. For circuit B where $I_A \neq I_B$, derating information can be calculated as follows:

(6) $T_{R(MAX)} = T_{J(MAX)} - \Delta T_{J1}$

Where $T_{R(MAX)}$ is the reference temperature (either case or ambient)

ΔT_{J1} can be calculated using equation (3) in Note 1.

For example, to determine $T_{C(MAX)}$ for the following load conditions:

I_A = 3.1 A average with a peak of 11.2 A
I_B = 1.55 A average with a peak of 6.8 A

First calculate the peak to average ratio for I_A. $I_{(PK)}/I_{(AV)}$ = 11.2/1.55 = 7.23 (Note that the peak to average ratio is on a per diode basis.)

From Figure 11, for an average current of 3.1 A and an $I_{(PK)}/I_{(AV)}$ = 7.23 read $P_{T(AV)}$ = 4.8 watts or 1.2 watts/diode $\therefore$ $P_{D1} = P_{D3}$ = 1.2 watts.

Similarly, for a load current I_B of 1.55 A, diode #2 and diode #4 each see 0.775 A average resulting in an $I_{(PK)}/I_{(AV)} \approx 8.8$.

Thus, the package power dissipation for 1.55 A is 2.3 watts or 0.575 watts/diode $\therefore$ $P_{D2} = P_{D4}$ = 0.575 watts.

The maximum junction temperature occurs in diode #1 and #3. From equation (3) for diode #1 ΔT_{J1} = 9[1.2 +.65(.575) +.725 (1.2) + .725 (.575)]

$\Delta T_{J1} \approx 26^\circ C$

Thus $T_{C(MAX)}$ = 150-26 = 124°C

The total package dissipation in this example is:

$P_J = 2 \times 1.2 + 2 \times 0.575 \approx 3.6$ watts

(Note that although maximum $R_{\theta JC}$ is 10°C/watt, 9°C/watt is used in this example and on the derating data as it is unlikely that all four die in a given package would be at the maximum value.)

NOTE 3

Under typical wire terminal or printed circuit board mounting conditions, the thermal resistance between the diode junctions and the leads at the edge of the case is a small fraction of the thermal resistance from junction to ambient. Consequently, the lead temperature is very close to the junction temperature. Therefore, it is recommended that the lead temperature be measured when the diodes are operating in prototype equipment, in order to determine if operation is within the diode temperature ratings. The lead having the highest thermal resistance to the ambient will yield readings closest to the junction temperature. By measuring temperature as outlined, variations of junction to ambient thermal resistance, caused by the amount of surface area of the terminals or printed circuit board and the degree of air convection, as well as proximity of other heat sources cease to be important design considerations.

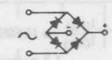
MOTOROLA

MDA2500 series

RECTIFIER ASSEMBLY

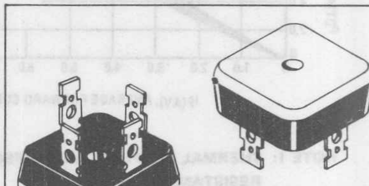
. . . utilizing individual void-free molded MR2500 Series rectifiers, interconnected and mounted on an electrically isolated aluminum heat sink by a high thermal-conductive epoxy resin.

- 400 Ampere Surge Capability
- Electrically Isolated Base – 1800 Volts
- UL Recognized
- Cost Effective in Lower Current Applications



SINGLE-PHASE FULL-WAVE BRIDGE

25 AMPERES 50–1000 VOLTS



MAXIMUM RATINGS

Rating (Per Diode)	Symbol	MDA 2500	2501	2502	2504	2506	2508	2510	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
DC Output Voltage Resistive Load	Vdc	30	62	124	250	380	500	630	Volts
Capacitive Load	Vdc	50	100	200	400	600	800	1000	Volts
Sine Wave RMS Input Voltage	V_R (RMS)	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (Single phase bridge resistive load, 60 Hz, $T_C = 55^{o}C$)	I_O	← 25 →							Amp
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions)	I_{FSM}	← 400 →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -65 to +175 →							^{o}C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Typ	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$			$^{o}C/W$
Each Die		8.0	10	
Total Bridge		2.0	2.8	

ELECTRICAL CHARACTERISTICS ($T_C = 25^{o}C$ unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) ($i_F = 40$ A)	v_F	–	0.95	1.05	Volts
Reverse Current (Per Diode) (Rated V_R)	I_R	–	–	0.10	mA

MECHANICAL CHARACTERISTICS

CASE: Plastic case with an electrically isolated aluminum base.

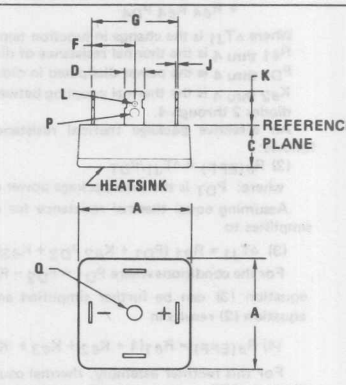
POLARITY: Terminal designation embossed on case:
+DC output
–DC output
AC not marked

MOUNTING POSITION: Bolt down. Highest heat transfer efficiency accomplished through the surface opposite the terminals. Use silicone heat sink compound on mounting surface for maximum heat transfer.

WEIGHT: 25 grams (approx.)

TERMINALS: Suitable for fast-on connections. Readily solderable, corrosion resistant. Soldering recommended for applications greater than 15 amperes.

MOUNTING TORQUE: 20 in. lb. max.



NOTES:
1. DIMENSION "Q" SHALL BE MEASURED ON HEATSINK SIDE OF PACKAGE.
2. DIMENSIONS "F" AND "G" SHALL BE MEASURED AT THE REFERENCE PLANE.

DIM	MILLIMETERS MIN	MAX	INCHES MIN	MAX
A	25.65	26.16	1.010	1.030
C	12.44	13.97	0.490	0.550
D	6.10	6.60	0.240	0.260
F	10.01	10.49	0.394	0.413
G	19.99	21.01	0.787	0.827
J	0.71	0.86	0.028	0.034
K	9.52	11.43	0.375	0.450
L	1.52	2.06	0.060	0.081
P	2.79	2.92	0.110	0.115
Q	4.42	4.67	0.174	0.184

CASE 309A-03

FIGURE 1 – FORWARD VOLTAGE

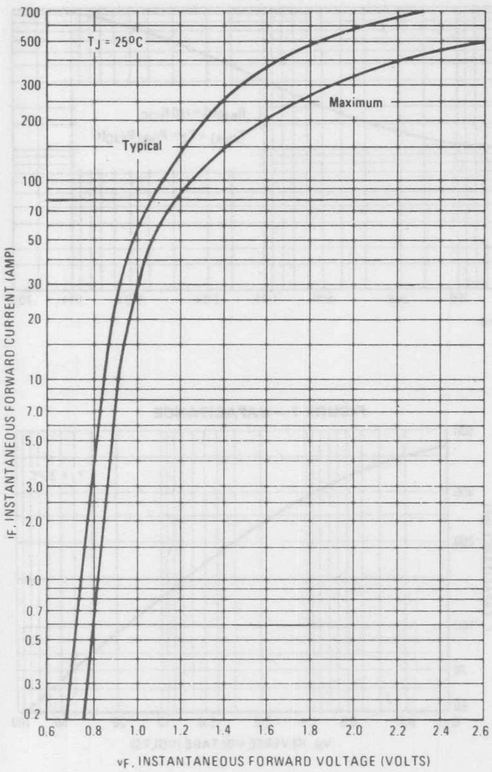


FIGURE 2 – NON-REPETITIVE SURGE CURRENT

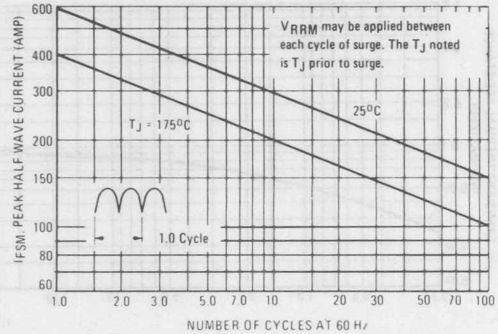


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

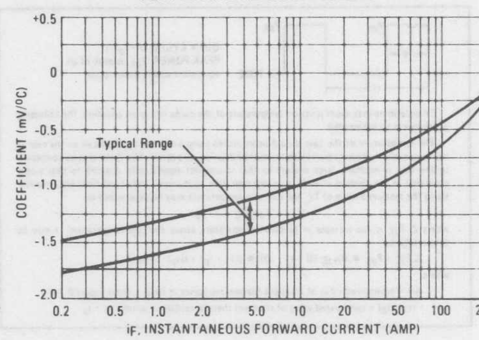


FIGURE 4 – CURRENT DERATING

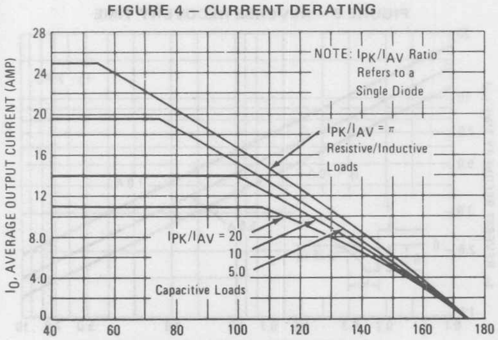


FIGURE 5 – FORWARD POWER DISSIPATION

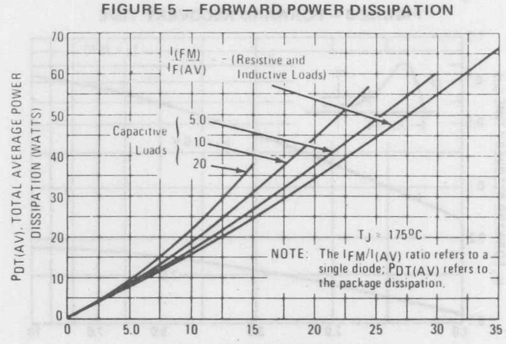
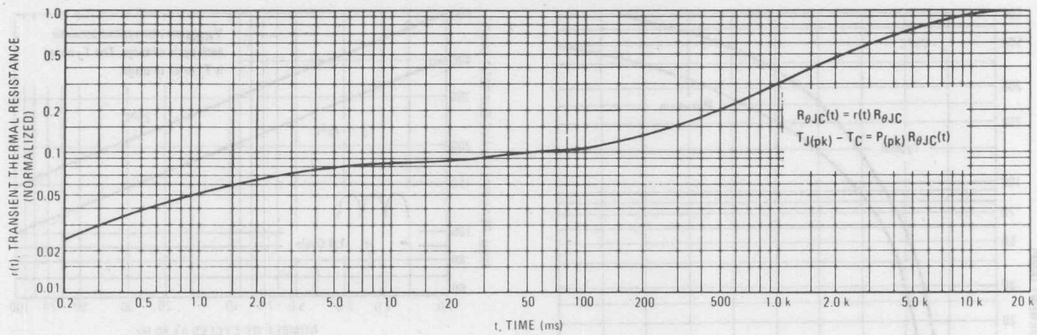
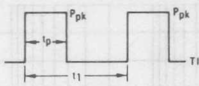


FIGURE 6 – TYPICAL THERMAL RESPONSE



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC}\,[D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.,
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

FIGURE 7 – CAPACITANCE

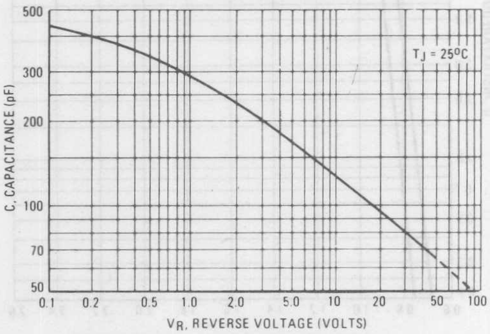


FIGURE 8 – FORWARD RECOVERY TIME

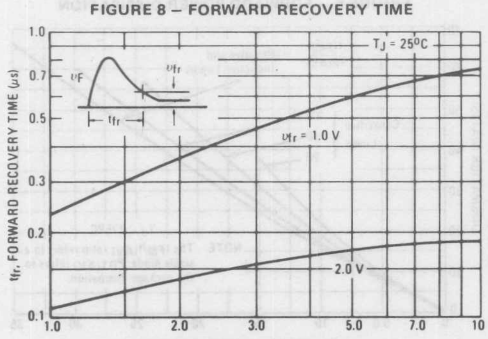
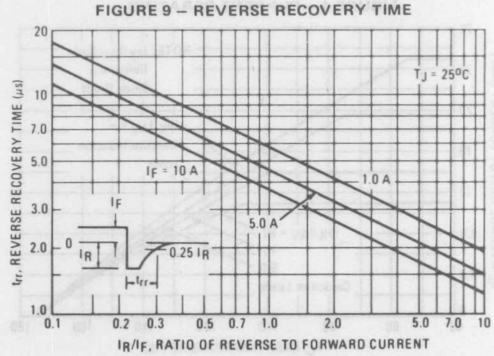


FIGURE 9 – REVERSE RECOVERY TIME



AMBIENT TEMPERATURE DERATING INFORMATION

FIGURE 10A – THERMALLOY HEAT SINK 6005B

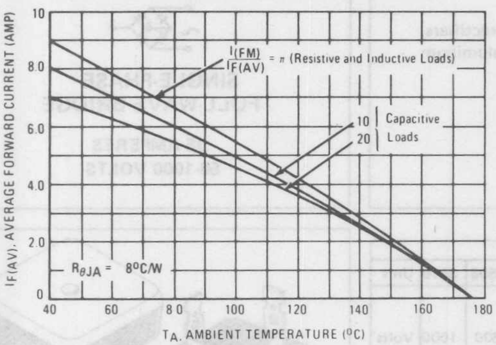
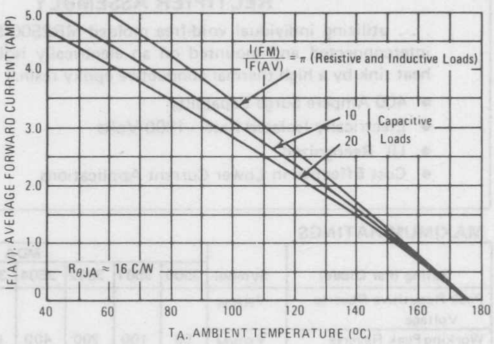


FIGURE 10B – IERC HEAT SINK UP3



NOTE 2: THERMAL COUPLING AND EFFECTIVE THERMAL RESISTANCE

In multiple chip devices where there is coupling of heat between die, the junction temperature can be calculated as follows:

(1) $\Delta T_{J1} = R_{\theta 1}P_{D1} + R_{\theta 2}K_{\theta 2}P_{D2} + R_{\theta 3}K_{\theta 3}P_{D3} + R_{\theta 4}K_{\theta 4}P_{D4}$

where ΔT_{J1} is the change in junction temperature of diode 1, $R_{\theta 1}$ through 4 is the thermal resistance of diodes 1 through 4, P_{D1} through 4 is the power dissipated in diodes 1 through 4, $K_{\theta 2}$ through 4 is the thermal coupling between diode 1, and diodes 2 through 4.

An effective package thermal resistance can be defined as follows:

(2) $R_{\theta(EFF)} = \Delta T_{J1}/P_{DT}$

where P_{DT} is the total package power dissipation.

Assuming equal thermal resistance for each die, equation (1) simplifies to

(3) $\Delta T_{J1} = R_{\theta 1}(P_{D1} + K_{\theta 2}P_{D2} + K_{\theta 3}P_{D3} + K_{\theta 4}P_{D4})$

For the conditions where $P_{D1} = P_{D2} = P_{D3} = P_{D4}$, $P_{DT} = 4\,P_{D1}$, equation (3) can be further simplified and by substituting into equation (2) results in

(4) $R_{\theta(EFF)} = R_{\theta 1}(1 + K_{\theta 2} + K_{\theta 3} + K_{\theta 4})/4$

When the case is used as a reference point, coupling between opposite die is negligible for the MDA2500, and coupling between adjacent die is approximately 6%.

NOTE 3: SPLIT LOAD DERATING INFORMATION

Bridge rectifiers are used in two basic configurations as shown by circuits A and B of Figure 11. The current derating data of Figure 4 applies to the standard bridge circuit (A) where $I_A = I_B$. For circuit B where $I_A \neq I_B$, derating information can be calculated as follows:

(6) $T_{R(max)} = T_{J(max)} - \Delta T_{J1}$

Where $T_{R(max)}$ is the reference temperature (either case or ambient), ΔT_{J1} can be calculated using equation (3) in Note 2.

For example, to determine $T_{C(max)}$ for the MDA2500 with the following capacitive load conditions:

I_A = 20 A average with a peak of 60 A,
I_B = 10 A average with a peak of 70 A,

first calculate the peak to average ratio for I_A. $I_{(PK)}/I_{(AV)}$ = 60/10 = 6.0. (Note that the peak to average ratio is on a per diode basis and each diode provides 10 A average.)

From Figure 5, for an average current of 20 A and an $I_{(PK)}/I_{(AV)}$ = 6.0, read $P_{DT(AV)}$ = 40 watts or 10 watts/diode. Thus $P_{D1} = P_{D3}$ = 10 watts.

Similarly, for a load current I_B of 10 A, diode #2 and diode #4 each see 5.0 A average resulting in an $I_{(PK)}/I_{(AV)}$ = 14. Thus, the package power dissipation for 10 A is 20 watts or 5.0 watts/diode. Therefore, $P_{D2} = P_{D4}$ = 5.0 watts.

The maximum junction temperature occurs in diodes #1 and #3. From equation (3) for diode #1,

$$\Delta T_{J1} = 10[10 + 0(5) + 0.06(10) + 0.06(5)]$$

$$\Delta T_{J1} \approx 109^{\circ}C.$$

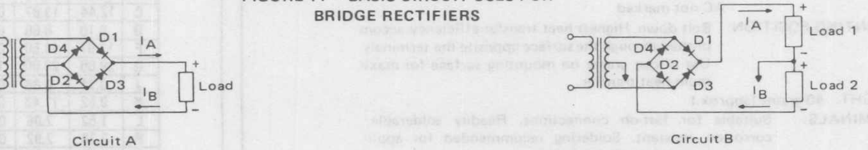
Thus, $T_{C(max)} = 175 - 109 = 66^{\circ}C$.

The total package dissipation in this example is

$$P_{DT(AV)} = 2 \times 10 + 2 \times 5.0 = 30 \text{ watts},$$

which must be considered when selecting a heat sink.

FIGURE 11 – BASIC CIRCUIT USES FOR BRIDGE RECTIFIERS



MOTOROLA

MDA3500 series

(MDA3500, MDA3501, MDA3502, MDA3504, MDA3506, MDA3508 MDA3510)

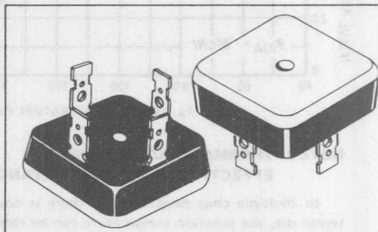
RECTIFIER ASSEMBLY

. . . utilizing individual void-free molded MR2500 Series rectifiers, interconnected and mounted on an electrically isolated aluminum heat sink by a high thermal-conductive epoxy resin.

- 400 Ampere Surge Capability
- Electrically Isolated Base –1800 Volts
- UL Recognized
- Cost Effective in Lower Current Applications

SINGLE-PHASE FULL-WAVE BRIDGE

35 AMPERES
50-1000 VOLTS



MAXIMUM RATINGS

Rating (Per Diode)	Symbol	MDA 3500	3501	3502	3504	3506	3508	3510	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
DC Output Voltage Resistive Load Capacitive Load	 Vdc Vdc	 30 50	 62 100	 124 200	 250 400	 380 600	 500 800	 630 1000	 Volts Volts
Sine Wave RMS Input Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (Single phase bridge resistive load, 60 Hz, $T_C = 55°C$)	I_O	← 35 →							Amp
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions)	I_{FSM}	← 400 →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -65 to +175 →							°C

THERMAL CHARACTERISTICS (Total Bridge)

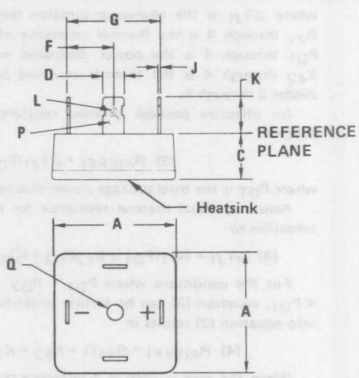
Characteristic	Symbol	Typ	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.4	1.87	°C/W

ELECTRICAL CHARACTERISTICS ($T_C = 25°C$ unless otherwise noted).

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (Per Diode) ($i_F = 55$ A)	v_F	–	1.0	1.1	Volts
Reverse Current (Per Diode) (Rated V_R)	I_R	–	–	0.10	mA

MECHANICAL CHARACTERISTICS

CASE: Plastic case with an electrically isolated aluminum base.
POLARITY: Terminal-designation embossed on case
+DC output
-DC output
AC not marked
MOUNTING POSITION: Bolt down. Highest heat transfer efficiency accomplished through the surface opposite the terminals. Use silicon grease on mounting surface for maximum heat transfer.
WEIGHT: 40 grams (approx.)
TERMINALS: Suitable for fast-on connections. Readily solderable, corrosion resistant. Soldering recommended for applications greater than 15 Amperes.
MOUNTING TORQUE: 20 in. lb. Max.



NOTE:
1. DIM "Q" SHALL BE MEASURED ON HEATSINK SIDE OF PKG.
2. DIMENSIONS F AND G SHALL BE MEASURED AT THE REFERENCE PLANE.

DIM	MILLIMETERS MIN	MAX	INCHES MIN	MAX
A	34.80	35.18	1.370	1.385
C	12.44	13.97	0.490	0.550
D	6.10	6.60	0.240	0.260
F	13.97	14.50	0.550	0.571
G	28.00	29.00	1.100	1.142
J	0.71	0.86	0.028	0.034
K	9.52	11.43	0.375	0.450
L	1.52	2.06	0.060	0.081
P	2.79	2.92	0.110	0.115
Q	4.32	4.83	0.170	0.190

CASE 309A-02

FIGURE 1 – FORWARD VOLTAGE

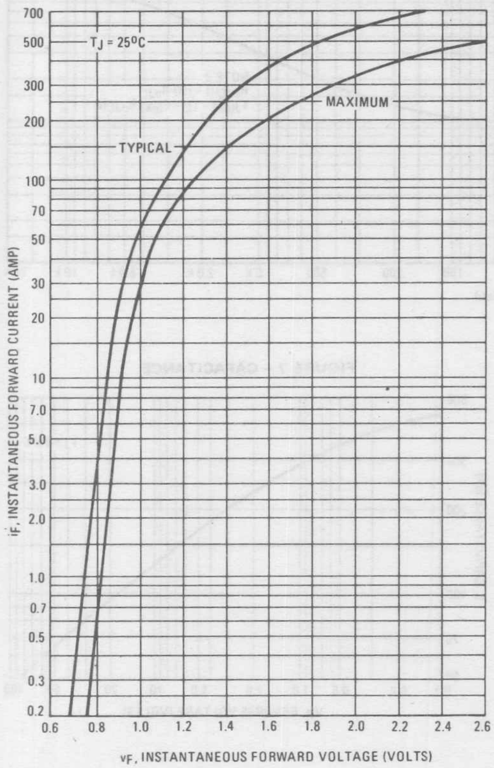


FIGURE 2 – NON-REPETITIVE SURGE CURRENT

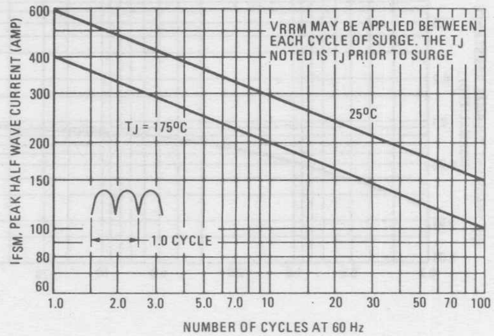


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

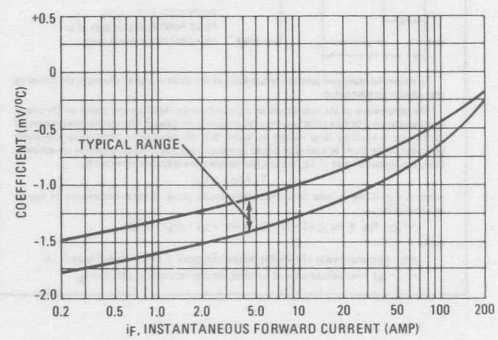


FIGURE 4 – CURRENT DERATING

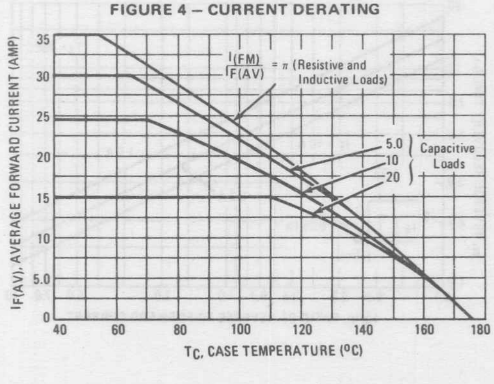


FIGURE 5 – FORWARD POWER DISSIPATION

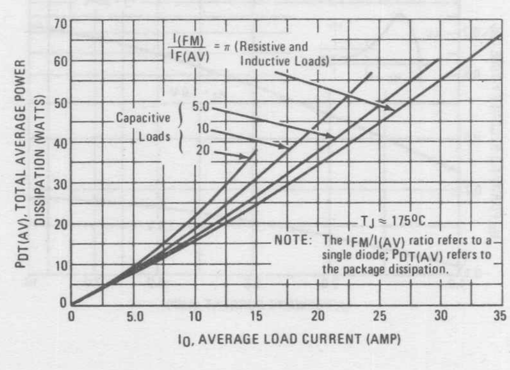
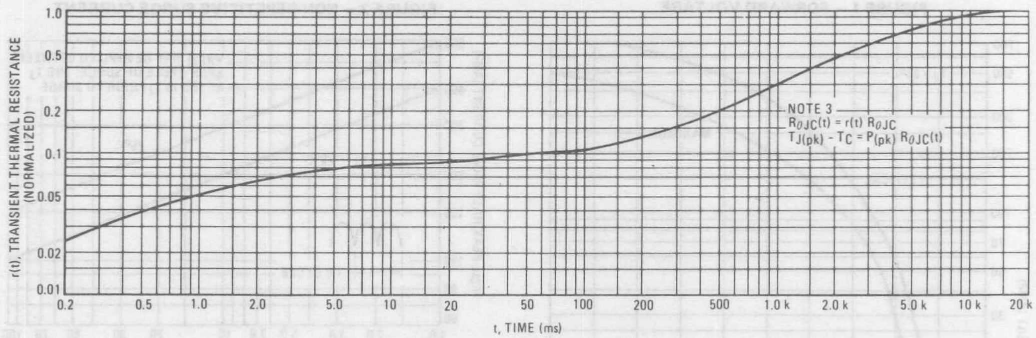
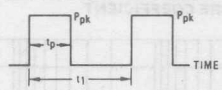


FIGURE 6 – TYPICAL THERMAL RESPONSE



NOTE 1



DUTY CYCLE, $D = t_p/t_1$.
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 8, i.e.,

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

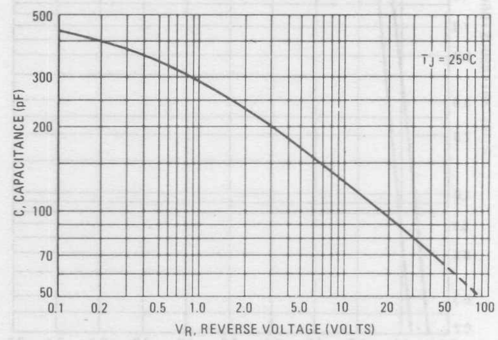


FIGURE 8 – FORWARD RECOVERY TIME

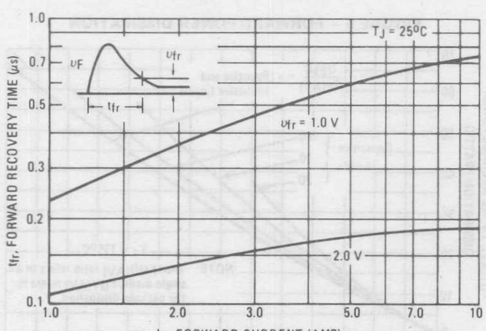
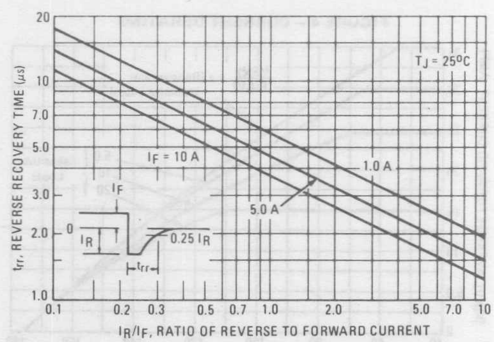


FIGURE 9 – REVERSE RECOVERY TIME



AMBIENT TEMPERATURE DERATING INFORMATION

FIGURE 10A – THERMALLOY HEATSINK 6005B

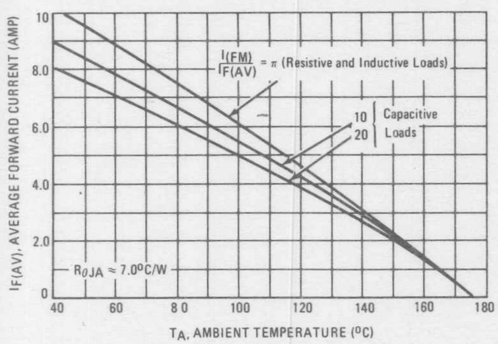
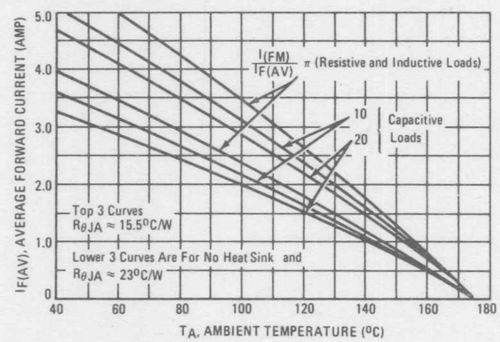


FIGURE 10B – IERC HEATSINK UP3 AND NO HEATSINK



NOTE 2: THERMAL COUPLING AND EFFECTIVE THERMAL RESISTANCE

In multiple chip devices where there is coupling of heat between die, the junction temperature can be calculated as follows:

(1) $\Delta T_{J1} = R_{\theta 1} P_{D1} + R_{\theta 2} K_{\theta 2} P_{D2} + R_{\theta 3} K_{\theta 3} P_{D3} + R_{\theta 4} K_{\theta 4} P_{D4}$

Where ΔT_{J1} is the change in junction temperature of diode 1

$R_{\theta 1}$ thru 4 is the thermal resistance of diodes 1 through 4

P_{D1} thru 4 is the power dissipated in diodes 1 through 4

$K_{\theta 2}$ thru 4 is the thermal coupling between diode 1 and diodes 2 through 4.

An effective package thermal resistance can be defined as follows:

(2) $R_{\theta(EFF)} = \Delta T_{J1}/P_{DT}$

Where: P_{DT} is the total package power dissipation

Assuming equal thermal resistance for each die, equation (1) simplifies to

(3) $\Delta T_{J1} = R_{\theta 1} (P_{D1} + K_{\theta 2} P_{D2} + K_{\theta 3} P_{D3} + K_{\theta 4} P_{D4})$

For the condiitons where $P_{D1} = P_{D2} = P_{D3} = P_{D4}$, $P_{DT} = 4 P_{D1}$, equation (3) can be further simplified and by substituting into equation (2) results in

(4) $R_{\theta(EFF)} = R_{\theta 1} (1 + K_{\theta 2} + K_{\theta 3} + K_{\theta 4})/4$

When the case is used as a reference point, coupling between die is neglegible for the MDA3500. When the bridge is used without a heatsink, coupling between die is approximately 70% and $R_{\theta 1}$ is 30°C/W,

$\therefore R_{\theta(EFF)} = 30 [1 + (3)(.7)]/4 = 23°C/W$

NOTE 3: SPLIT LOAD DERATING INFORMATION

Bridge rectifiers are used in two basic configurations as shown by circuits A and B of Figure 11. The current derating data of Figure 4 applies to the standard bridge circuit (A) where $I_A = I_B$. For circuit B where $I_A = I_B$, derating information can be calculated as follows:

(6) $T_{R(Max)} = T_{J(Max)} - \Delta T_{J1}$

Where $T_{R(Max)}$ is the reference temperature (either case or ambient)

ΔT_{J1} can be calculated using equation (3) in Note 2.

For example, to determine $T_{C(Max)}$ for the MDA3500 with the following capacitive load condiitons.

I_A = 20 A average with a peak of 60 A

I_B = 10 A average with a peak of 70 A

First calculate the peak to average ratio for I_A. $I_{(PK)}/I_{(AV)}$ = 60/10 = 6.0. (Note that the peak to average ratio is on a per diode basis and each diode provides 10 A average).

From Figure 5, for an average current of 20 A and an $I_{(PK)}/I_{(AV)}$ = 6.0 read $P_{DT(AV)}$ = 40 watts or 10 watts/diode. Thus $P_{D1} = P_{D3}$ = 10 watts.

Similarly, for a load current I_B of 10 A, diode #2 and diode #4 each see 5.0 A average resulting in an $I_{(PK)}/I_{(AV)}$ = 14.

Thus, the package power dissipation for 10 A is 20 watts or 5.0 watts/diode $\therefore P_{D2} = P_{D4}$ = 5.0 watts.

The maximum junction temperature occurs in diode #1 and #3. From equation (3) for diode #1 ΔT_{J1} = (7.5) (10), since coupling is negligible.

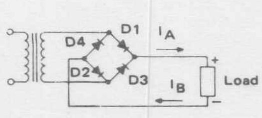
$\Delta T_{J1} \approx 75°C$

Thus $T_{C(Max)}$ = 175 -75 = 100°C

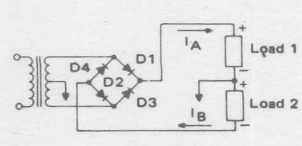
The total package dissipation in this example is:

$P_{DT(AV)} = 2 \times 10 + 2 \times 5.0 = 30$ watts, which must be considered when selecting a heat sink.

FIGURE 11– BASIC CIRCUIT USES FOR BRIDGE RECTIFIERS



Circuit A



Circuit B

NOTES

NOTES

MOTOROLA

MR1-1000
MR1-1200
MR1-1400
MR1-1600

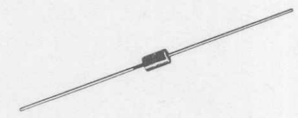
AXIAL LEAD SILICON RECTIFIERS

. . . designed for television "damper" diode service and other high voltage industrial/consumer applications.

- High Current Handling — 1.0 Ampere at 75°C
- Medium Recovery Characteristics
- Low Forward Voltage

HIGH VOLTAGE
LEAD MOUNTED
SILICON RECTIFIERS

1000, 1200, 1400, 1600 VOLTS
1 AMPERE



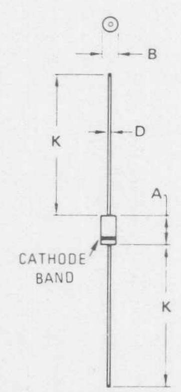
MAXIMUM RATINGS

Rating	Symbol	MR1-1000	MR1-1200	MR1-1400	MR1-1600	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	1000	1200	1400	1600	Volts
Average Rectified Forward Current (Single phase, resistive load, $R_{\theta JA}$ = 85°C/W, T_A = 75°C) (1)	I_O	← 1.0 →				Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions.)	I_{FSM}	← 30 (for 1 cycle) →				Amp
Operating and Storage Junction Temperature Range (2)	T_J, T_{stg}	← -65 to +175 →				°C

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic	Symbol	Typ	Max	Unit
Maximum Instantaneous Forward Voltage (i_F = 1.0 Amp, T_J = 25°C) (i_F = 3.14 Amp, T_J = 25°C)	v_F	 0.95 1.1	 1.1 1.3	Volts
Maximum Reverse Current (rated dc voltage) T_J = 25°C T_J = 100°C	I_R	 0.2 12	 10 100	μA
Capacitance (V_R = 50 volts, f = 1.0 MHz)	C	4.0	7.0	pF
Reverse Recovery Time (I_F = 20 mA, I_R = 2.0 mA)	t_{rr}	17	25	μs
Forward Recovery Time (I_F = 20 mA, V_{fr} = 2.0 V)	t_{fr}	0.7	1.0	μs

(1) Must be derated for reverse power dissipation. See note on Page 3.
(2) Derate as shown in Figure 4.



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

CASE 59-04

MECHANICAL CHARACTERISTICS

CASE: Void free, Transfer Molded
MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 350°C, 3/8" case for 10 seconds at 5 lbs. tension
FINISH: All external surfaces are corrosion-resistant, leads are readily solderable
POLARITY: Cathode indicated by color band
WEIGHT: 0.40 Grams (approximately)

FIGURE 1 – FORWARD POWER DISSIPATION

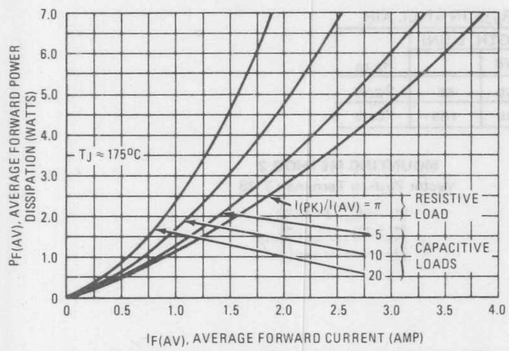


FIGURE 2 – CURRENT DERATING

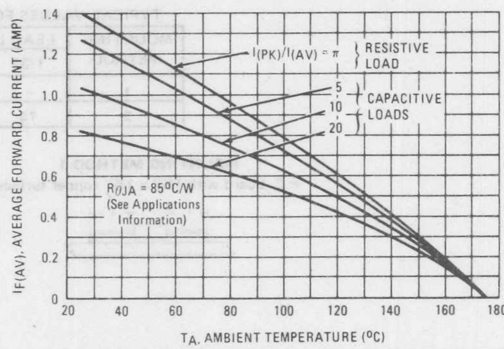


FIGURE 3 – NON-REPETITIVE SURGE CURRENT

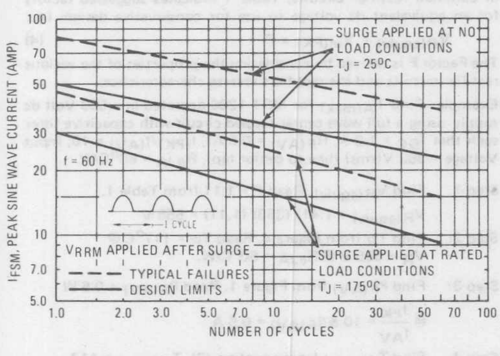
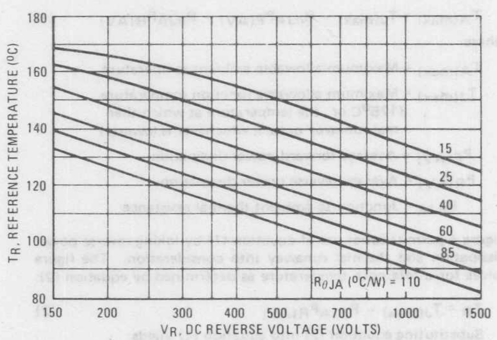


FIGURE 4 – MAXIMUM REFERENCE TEMPERATURE



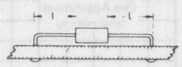
APPLICATIONS INFORMATION

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN)			$R_{\theta JA}$
	1/32	3/8	1	
1	–	60	85	°C/W
2	73	85	103	°C/W

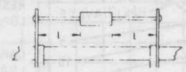
MOUNTING METHOD 1

P.C. Board with 1½" x 1½" copper surface



MOUNTING METHOD 2

Vector Push-In Terminals T-28



Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 50 volts. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}P_{F(AV)} - R_{\theta JA}P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (175°C or the temperature at which thermal runaway occurs, whichever is lowest.)

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figure 4 permits easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figure solves for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA}P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 175°C when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figure 4 as a difference in the rate of change of the slope in the vicinity of 160°C. The data of Figure 4 is based upon dc conditions. For use in common rectifier circuits, Table 1 indicates suggested factors for an equivalent dc voltage to use for conservative design: i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \quad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the rectifiers reverse characteristics.

Example: Find $T_{A(max)}$ for MR1-1200 operated in a 500 Volt dc supply using a full wave center-tapped circuit with capacitive filter such that I_{DC} = 1.0 A, ($I_{F(AV)}$ = 0.5 A), $I_{(PK)}/I_{(AV)}$ = 10, Input Voltage = 353 V(rms) (line to center tap), $R_{\theta JA}$ = 60°C/W.

Step 1: Find $V_{R(equiv)}$. Read F = 1.11 from Table 1.
$V_{R(equiv)}$ = 1.41) (353) (1.11) = 555 V

Step 2: Find T_R from Figure 4. Read T_R = 117°C @ V_R = 555 V @ $R_{\theta JA}$ = 60°C/W.

Step 3: Find $P_{F(AV)}$ from Figure 1. Read $P_{F(AV)}$ = 0.6 W @ $\frac{I_{PK}}{I_{AV}}$ = 10 & $I_{F(AV)}$ = 0.5 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 117 -(60) (0.6) = 81°C.

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave Center-Tapped*†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.45	1.11	0.45	0.55	0.90	1.11
Square Wave	0.61	1.22	0.61	0.61	1.22	1.22

*Note that $V_{R(PK)} \approx 2\ V_{in(PK)}$ †Use line to center tap voltage for V_{in}

![MOTOROLA]

MOTOROLA

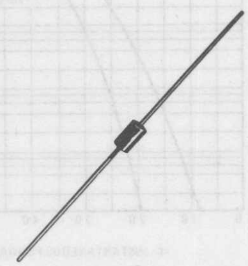
MR250-1 thru MR250-5

HIGH VOLTAGE, LOW CURRENT RECTIFIERS

. . . designed for use in applications where small packages are required. These devices feature high surge current capability and low reverse power loss.

HIGH VOLTAGE RECTIFIERS

250 MILLIAMPERES
1000-5000 VOLTS



MAXIMUM RATINGS ($T_A = 25^oC$ unless otherwise noted)

Rating	Symbol	MR250-1	MR250-2	MR250-3	MR250-4	MR250-5	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} $V_{R(RMS)}$	1000	2000	3000	4000	5000	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz, $T_A = 75^oC$)	I_O	← 250 →					mA
Peak Repetitive Forward Current $T_A = 75^oC$	I_{FRM}	← 2.0 →					Amp
Non-Repetitive Peak Surge Current (superimposed on rated current at rated voltage, $T_A = 75^oC$)	I_{FSM}	← 20 (for 1/2 cycle) →					Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -65 to +150 →					^oC

THERMAL CHARACTERISTICS

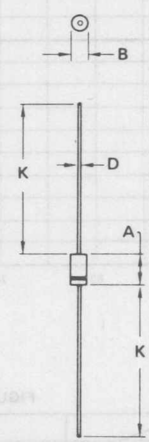
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (1 inch lead length)	$R_{\theta JA}$	100	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Instantaneous Forward Voltage ($i_F = 0.785$ Adc, $T_A = 25^oC$)	v_F	3.75	Volts
DC Reverse Current, Rated V_R $T_A = 25^oC$ $T_A = 100^oC$	I_R	 10 50	μA

MECHANICAL CHARACTERISTICS

CASE: Void free, transfer molded
FINISH: All external surfaces corrosion-reisitant and leads readily solderable
POLARITY: Indicated by polarity band
MOUNTING POSITIONS: Any
WEIGHT: 0.40 Gram (approx)
MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 350^oC, 3/8" from case for 10 seconds



NOTE:
1. POLARITY MARK – CATHODE BAND

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	11.56	11.81	0.455	0.465
B	3.73	3.89	0.147	0.153
D	0.76	0.86	0.030	0.034
K	24.13	29.21	0.950	1.150

CASE 169-02

FIGURE 1 – MAXIMUM FORWARD VOLTAGE

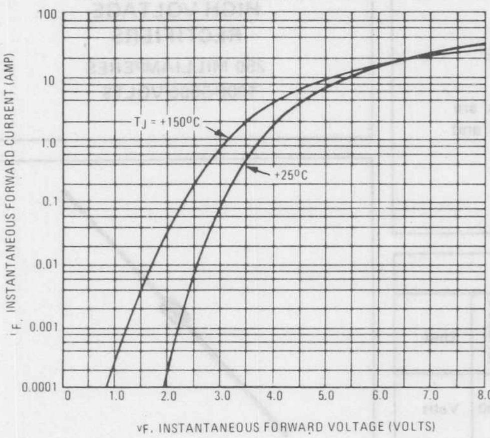


FIGURE 2 – TYPICAL REVERSE CURRENT

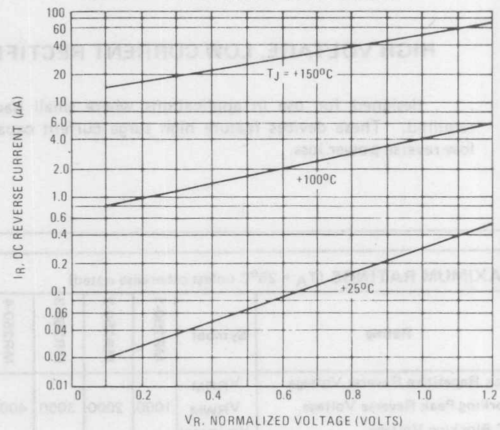


FIGURE 3 – CURRENT DERATING

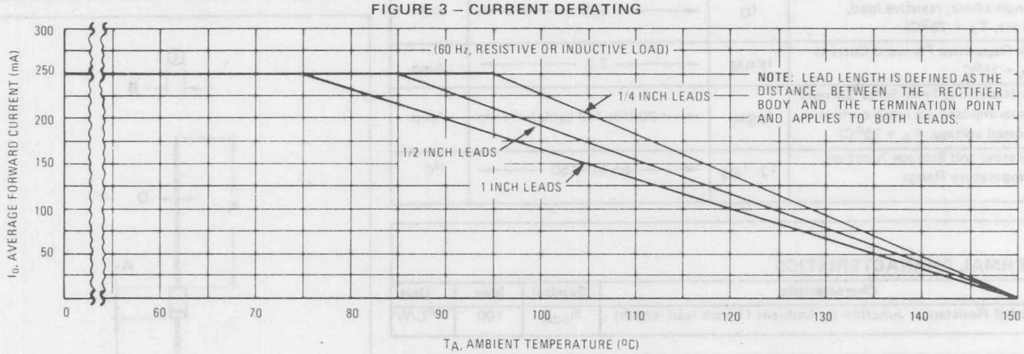
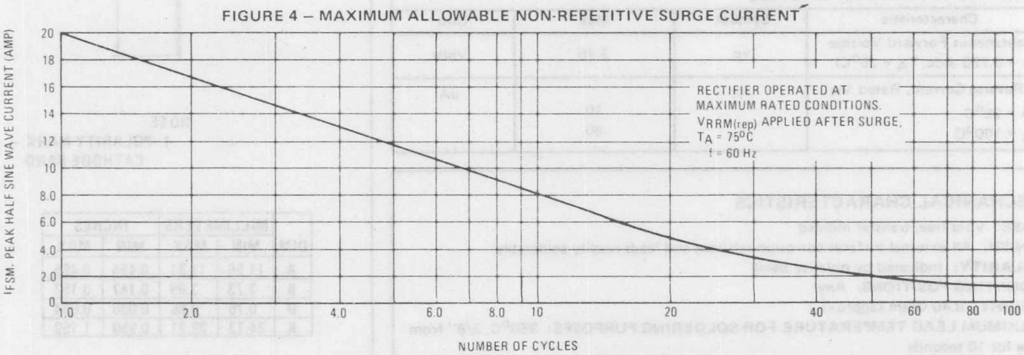


FIGURE 4 – MAXIMUM ALLOWABLE NON-REPETITIVE SURGE CURRENT



![MOTOROLA]

MOTOROLA

MR500 MR501 MR502 MR504 MR506 MR508 MR510

Designers Data Sheet

MINIATURE SIZE, AXIAL LEAD MOUNTED STANDARD RECOVERY POWER RECTIFIERS

. . . designed for use in power supplies and other applications having need of a device with the following features:

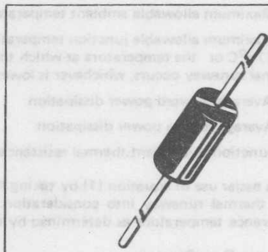
- High Current to Small Size
- High Surge Current Capability
- Low Forward Voltage Drop
- Void-Free Economical Plastic Package
- Available in Volume Quantities

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

STANDARD RECOVERY POWER RECTIFIERS

50-1000 VOLTS
3 AMPERE



MAXIMUM RATINGS

Rating	Symbol	MR500	MR501	MR502	MR504	MR506	MR508	MR510	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	450	650	850	1050	Volts
Average Rectified Forward Current (Single phase resistive load, $T_Z = 95°C$, PC Board Mounting) (1) (EIA Standard Conditions L = 1/32", $T_L = 85°C$)	I_O	3.0 8.0							Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	100 (one cycle)							Amp
Operating and Storage Junction Temperature Range (2)	T_J, T_{stg}	−65 to +175							°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Recommended Printed Circuit Board Mounting, See Note 2 on Page 4).	$R_{\theta JA}$	28	°C/W

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (3) (i_F = 9.4 Amp, T_J = 175°C) (i_F = 9.4 Amp, T_J = 25°C)	v_F	 — —	 0.9 1.04	 1.0 1.1	Volts
Reverse Current (rated dc voltage) (3) T_J = 25°C T_J = 100°C	I_R	 — —	 0.1 2.8	 5.0 25	μA

(1) Derate for reverse power dissipation. See Note on Page 2.
(2) Derate as shown in Figure 1.
(3) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

MECHANICAL CHARACTERISTICS

Case: Void Free, Transfer Molded
Finish: External Leads are Plated, Leads are readily Solderable
Polarity: Indicated by Cathode Band
Weight: 1.1 Grams (Approximately)
Maximum Lead Temperature for Soldering Purposes:
300°C, 1/8" from case for 10 s at 5.0 lb. tension

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 200 volts. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA}P_{F(AV)} - R_{\theta JA}P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature ($175^{o}C$ or the temperature at which thermal runaway occurs, whichever is lowest.)

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figure 1 permits easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figure solves for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA}P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA}P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where $T_J = 175^{o}C$, when forward power is zero. The transition from one boundary condition to the other is evident on the curves of Figure 1 as a difference in the rate of change of the slope in the vicinity of $165^{o}C$. The data of Figure 1 is based upon dc conditions. For use in common rectifier circuits, Table 1 indicates suggested factors for an equivalent dc voltage to use for conservative design; i.e.:

$$V_{R(equiv)} = V_{in(PK)} \times F \quad (4)$$

The Factor F is derived by considering the properties of the various rectifier circuits and the rectifiers reverse characteristics.

Example: Find $T_{A(max)}$ for MR510 operated in a 400 Volt dc supply using a full wave center-tapped circuit with capacitive filter such that I_{DC} = 6.0 A, ($I_{F(AV)}$ = 3.0 A), $I_{(PK)}/I_{(AV)}$ = 10, Input Voltage = 283 V(rms) (line to center tap), $R_{\theta JA} = 28^{o}C/W$.

Step 1: Find $V_{R(equiv)}$. Read F = 1.11 from Table 1 ∴

$V_{R(equiv)}$ = 1.41)(283)(1.11) = 444 V

Step 2: Find T_R from Figure 1. Read $T_R = 167^{o}C$ @ V_R = 444 V & $R_{\theta JA} = 28^{o}C/W$.

Step 3: Find $P_{F(AV)}$ from Figure 8. Read $P_{F(AV)}$ = 4 W @ $\frac{I_{PK}}{I_{AV}}$ = 10 & $I_{F(AV)}$ = 3.0 A

Step 4: Find $T_{A(max)}$ from equation (3). $T_{A(max)}$ = 167-(28) (4) = $55^{o}C$.

TABLE I – VALUES FOR FACTOR F

Circuit	Half Wave		Full Wave, Bridge		Full Wave Center-Tapped*†	
Load	Resistive	Capacitive*	Resistive	Capacitive	Resistive	Capacitive
Sine Wave	0.45	1.11	0.45	0.55	0.90	1.11
Square Wave	0.61	1.22	0.61	0.61	1.22	1.22

*Note that $V_{R(PK)} \approx 2\ V_{in(PK)}$ †Use line to center tap voltage for V_{in}.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE

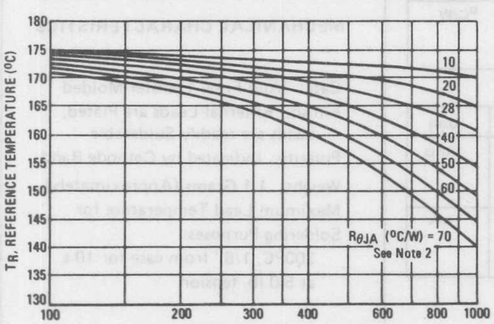
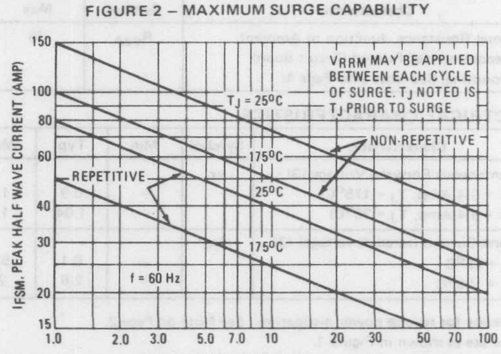


FIGURE 2 – MAXIMUM SURGE CAPABILITY



CURRENT DERATING
(Reverse Power Loss Neglected)

FIGURE 3 – PC BOARD MOUNTING

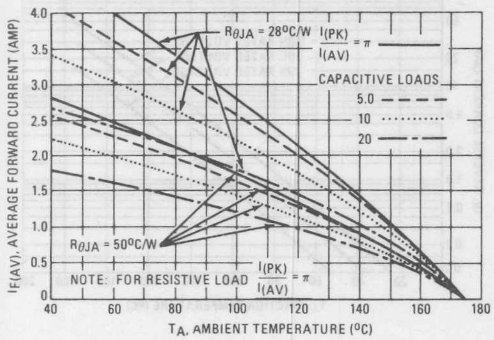


FIGURE 4 – SEVERAL LEAD LENGTHS

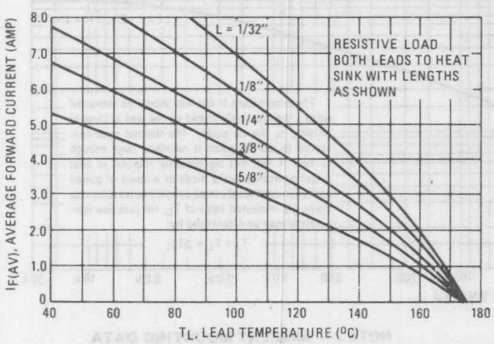


FIGURE 5 – 1/8" LEAD LENGTH

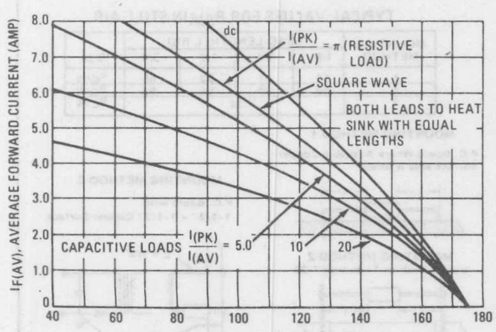


FIGURE 6 – MAXIMUM FORWARD VOLTAGE

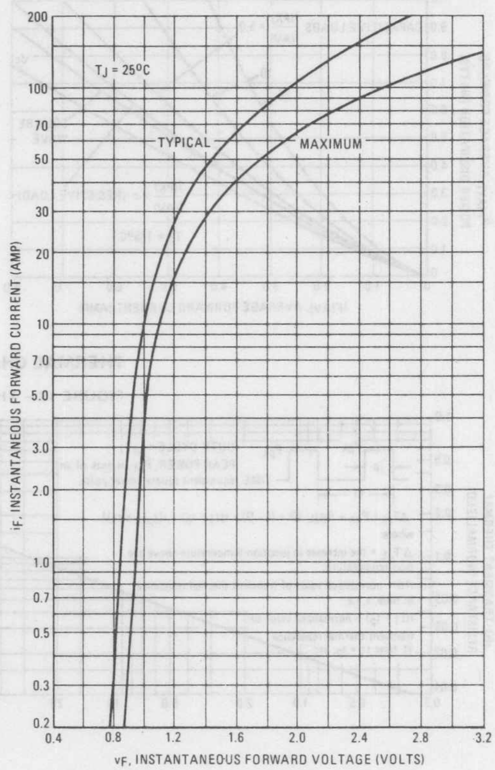


FIGURE 7 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

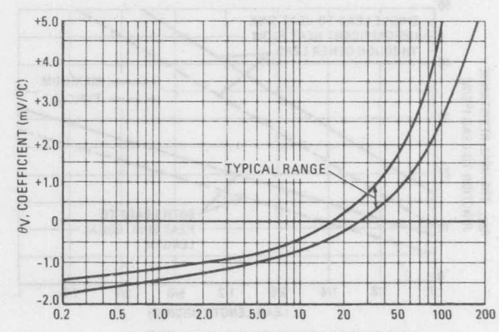


FIGURE 8 – FORWARD POWER DISSIPATION

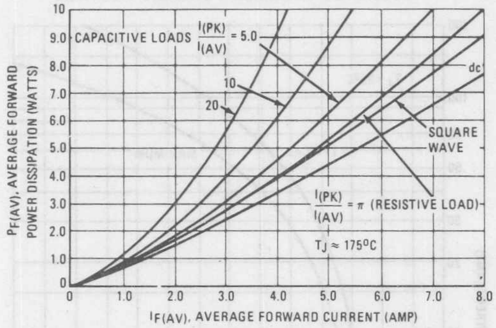
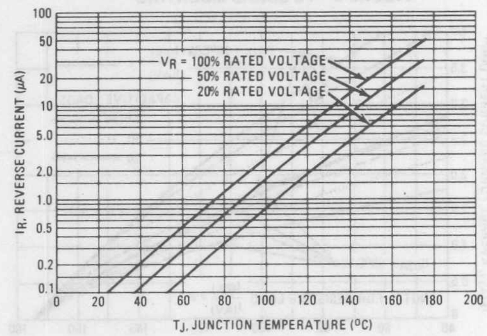


FIGURE 9 – TYPICAL REVERSE CURRENT



THERMAL CHARACTERISTICS

FIGURE 10 – THERMAL RESPONSE

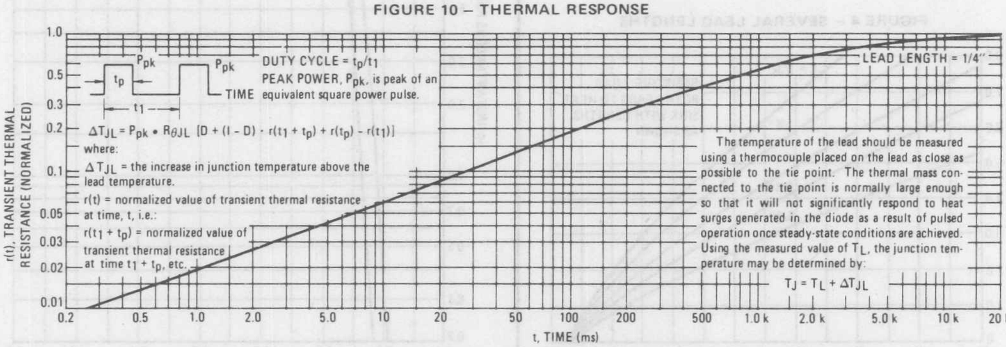
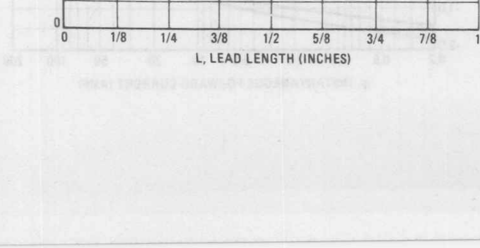


FIGURE 11 – STEADY-STATE THERMAL RESISTANCE



NOTE 2 – AMBIENT MOUNTING DATA

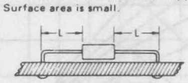
Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN)				$R_{\theta JA}$
	1/8	1/4	1/2	3/4	
1	50	51	53	55	$^oC/W$
2	58	59	61	63	$^oC/W$
3	28				$^oC/W$

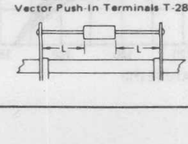
MOUNTING METHOD 1

P.C. Board Where Available Copper Surface area is small.



MOUNTING METHOD 2

Vector Push-In Terminals T-28



MOUNTING METHOD 3

P.C. Board with 1-1/2″ x 1-1/2″ Copper Surface

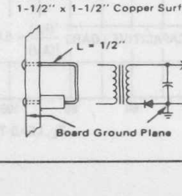
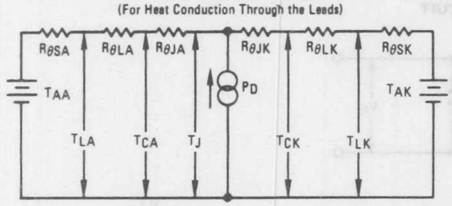


FIGURE 12 – APPROXIMATE THERMAL CIRCUIT MODEL

THERMAL CIRCUIT MODEL
(For Heat Conduction Through the Leads)



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Total Power Dissipation = $P_F + P_R$
P_F = Forward Power Dissipation
P_R = Reverse Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.)
Values for thermal resistance components are:

$R_{\theta L}$ = 46°C/W/IN. Typically and 48°C/W/IN Maximum.
$R_{\theta J}$ = 10°C/W Typically and 16°C/W Maximum.

The maximum lead temperature may be found as follows:

$$T_L = T_{J(max)} - \Delta T_{JL}$$

where $\Delta T_{JL} \approx R_{\theta JL}$

TYPICAL DYNAMIC CHARACTERISTICS
($T_J = 25°C$)

FIGURE 13 – FORWARD RECOVERY TIME

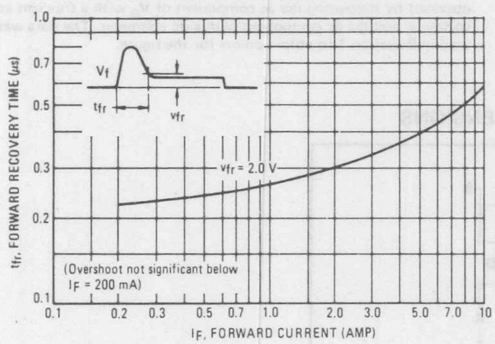


FIGURE 14 – REVERSE RECOVERY TIME

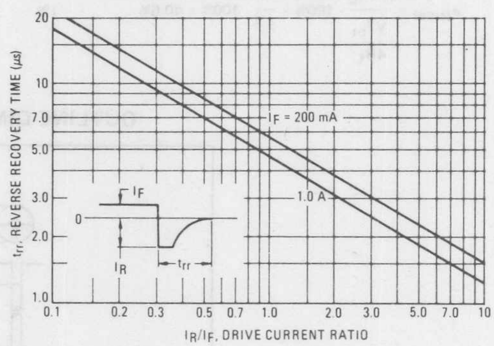


FIGURE 15 – RECTIFICATION WAVEFORM EFFICIENCY

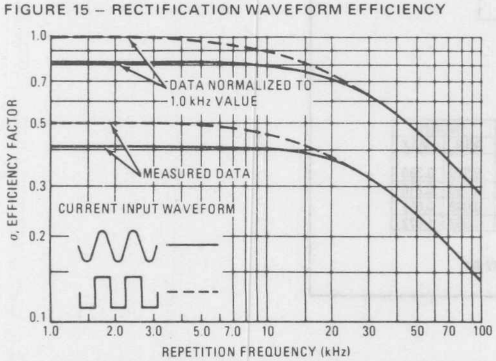
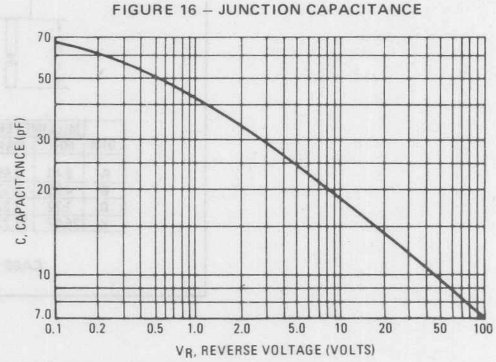
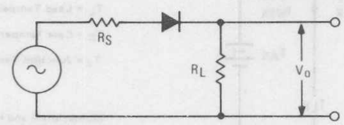


FIGURE 16 – JUNCTION CAPACITANCE



RECTIFIER EFFICIENCY NOTE

FIGURE 17 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 15 was calculated using the formula:

$$\sigma = \frac{P_{(dc)}}{P_{(rms)}} = \frac{\dfrac{V^2{}_o(dc)}{R_L}}{\dfrac{V^2{}_o(rms)}{R_L}} \cdot 100\% = \frac{V^2{}_o(dc)}{V^2{}_o(ac) + V^2{}_o(dc)} \cdot 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assumed lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\dfrac{V^2{}_m}{\pi^2 R_L}}{\dfrac{V^2{}_m}{4R_L}} \cdot 100\% = \frac{4}{\pi^2} \cdot 100\% = 40.6\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

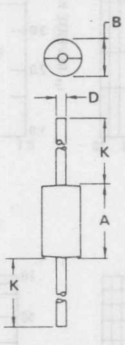
$$\sigma_{(square)} = \frac{\dfrac{V^2{}_m}{2R_L}}{\dfrac{V^2{}_m}{R_L}} \cdot 100\% = 50\% \quad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 14) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 15.

It should be emphasized that Figure 15 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_o with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for the figure.

OUTLINE DIMENSIONS



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	9.65	0.370	0.380
B	4.83	5.33	0.190	0.210
D	1.22	1.32	0.048	0.052
K	26.97	27.23	1.062	1.072

CASE 267-01

MOTOROLA

MR 750 SERIES

Designers Data Sheet

HIGH CURRENT LEAD MOUNTED RECTIFIERS

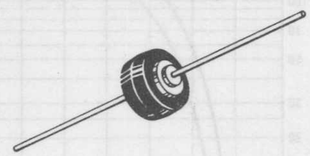
- Current Capacity Comparable To Chassis Mounted Rectifiers
- Very High Surge Capacity
- Insulated Case

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

HIGH CURRENT LEAD MOUNTED SILICON RECTIFIERS

50–1000 VOLTS
DIFFUSED JUNCTION



MAXIMUM RATINGS

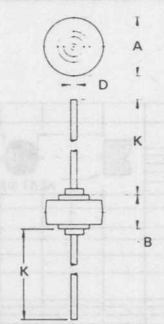
Characteristic	Symbol	MR750	MR751	MR752	MR754	MR756	MR758	MR760	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz peak)	V_{RSM}	60	120	240	480	720	960	1200	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	560	700	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz.) See Figures 5 and 6.	I_O	22 (T_L = 60°C, 1/8" Lead Lengths) 6.0 (T_A = 60°C, P.C. Board mounting)							Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	400 (for 1 cycle)							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	−65 to +175							°C

ELECTRICAL CHARACTERISTICS

Characteristic and Conditions	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage Drop (i_F = 100 Amp, T_J = 25=C)	v_F	1.25	Volts
Maximum Forward Voltage Drop (I_F = 6.0 Amp, T_A = 25°C, 3/8" leads)	V_F	0.90	Volts
Maximum Reverse Current (rated dc voltage) T_J = 25=C	I_R	0.25	mA
T_J = 100°C		1.0	

MECHANICAL CHARACTERISTICS

CASE: Void free, Transfer Molded
MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 350°C 3/8" from case for 10 seconds at 5.0 lbs. tension
FINISH: All external surfaces are corrosion-resistant, leads are readily solderable
POLARITY: Indicated by diode symbol
WEIGHT: 2.5 Grams (approx.)



NOTE:
1. CATHODE SYMBOL ON PKG.

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	10.03	10.29	0.395	0.405
B	5.94	6.25	0.234	0.246
D	1.27	1.35	0.050	0.053
K	25.15	25.65	0.990	1.010

CASE 194-01

FIGURE 1 – FORWARD VOLTAGE

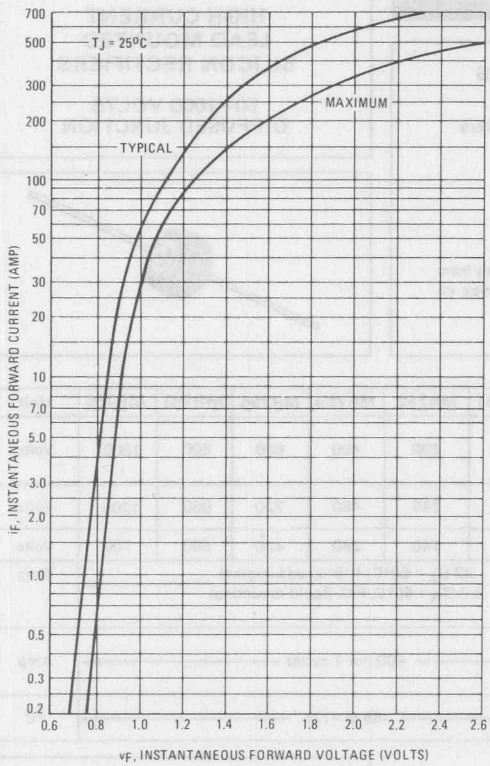


FIGURE 2 – MAXIMUM SURGE CAPABILITY

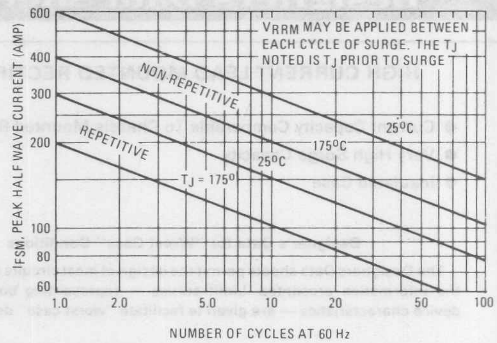


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

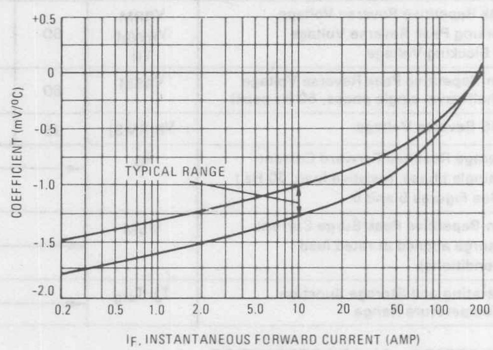


FIGURE 4 – TYPICAL TRANSIENT THERMAL RESISTANCE

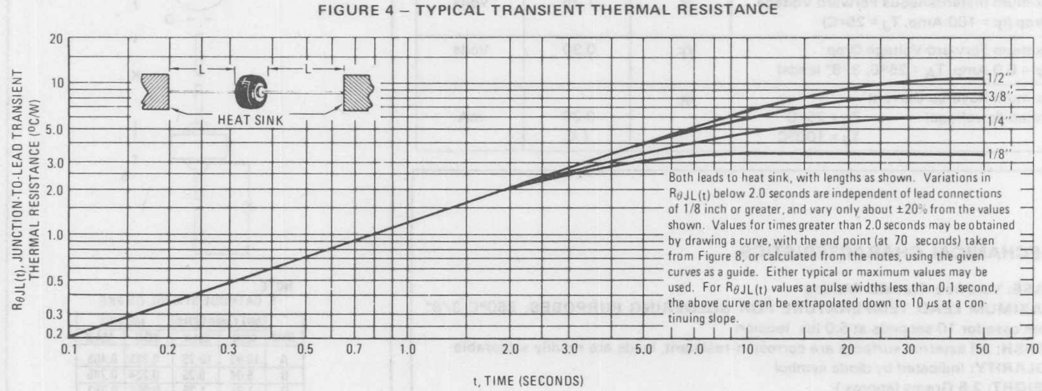


FIGURE 5 – MAXIMUM CURRENT RATINGS

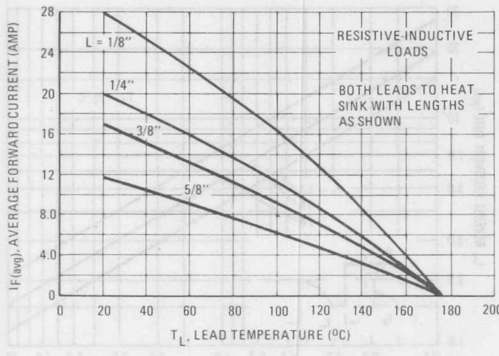


FIGURE 6 – MAXIMUM CURRENT RATINGS

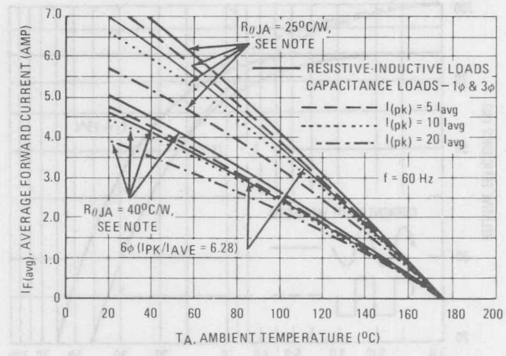


FIGURE 7 – POWER DISSIPATION

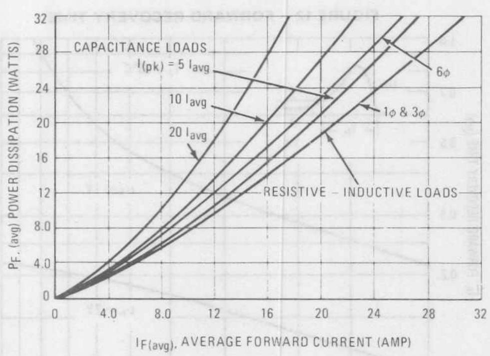
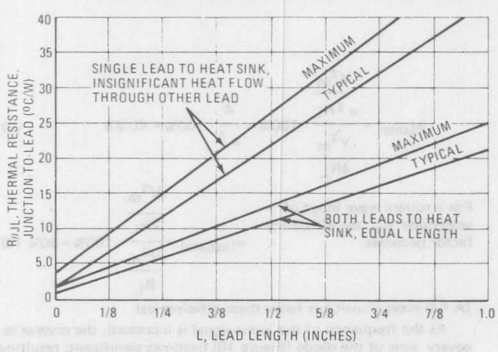


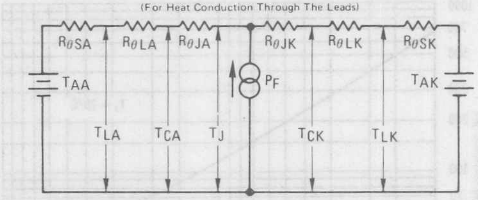
FIGURE 8 – STEADY STATE THERMAL RESISTANCE



NOTES

THERMAL CIRCUIT MODEL

(For Heat Conduction Through The Leads)



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. Lowest values occur when one side of the rectifier is brought as close as possible to the heat sink as shown below. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_F = Power Dissipation

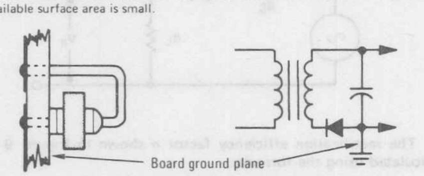
(Subscripts A and K refer to anode and cathode sides respectively.)

Values for thermal resistance components are:

$R_{\theta L}$ = 40°C/W/IN. Typically and 44°C/W/IN Maximum
$R_{\theta J}$ = 2°C/W Typically and 4°C/W Maximum

Since $R_{\theta J}$ is so low, measurements of the case temperature, T_C, will be approximately equal to junction temperature in practical lead mounted applications. When used as a 60 Hz rectifier, the slow thermal response holds $T_{J(PK)}$ close to $T_{J(AVG)}$. Therefore maximum lead temperature may be found from: $T_L = 175° - R_{\theta JL} P_F$. P_F may be found from Figure 7.

The recommended method of mounting to a P.C. board is shown on the sketch, where $R_{\theta JA}$ is approximately 25°C/W for a 1-1/2" x 1-1/2" copper surface area. Values of 40°C/W are typical for mounting to terminal strips or P.C. boards where available surface area is small.



Recommended mounting for half wave circuit

TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 9 – RECTIFICATION EFFICIENCY

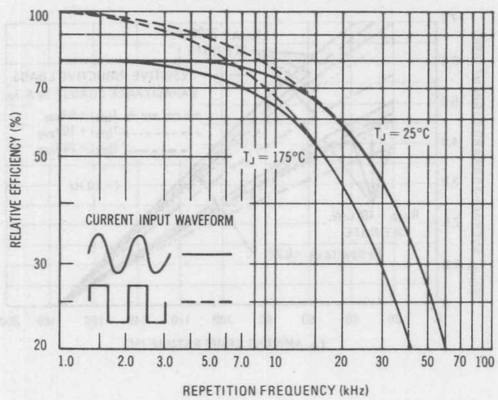


FIGURE 10 – REVERSE RECOVERY TIME

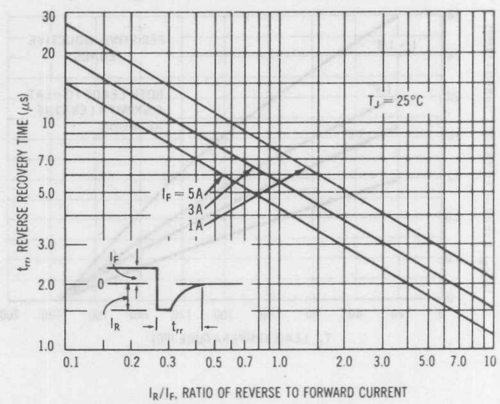


FIGURE 11 – JUNCTION CAPACITANCE

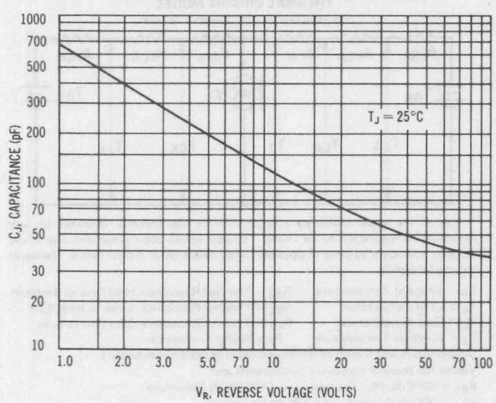


FIGURE 12 – FORWARD RECOVERY TIME

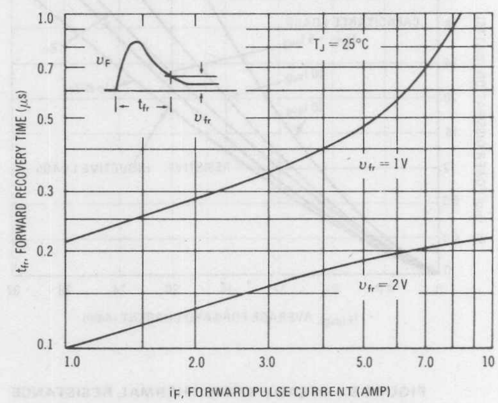
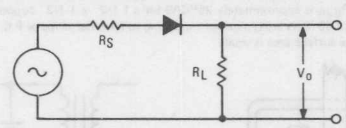


FIGURE 13 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 9 was calculated using the formula:

$$\sigma = \frac{P_{(dc)}}{P_{(rms)}} = \frac{\dfrac{V^2{}_o(dc)}{R_L}}{\dfrac{V^2{}_o(rms)}{R_L}} \cdot 100\% = \frac{V^2{}_o(dc)}{V^2{}_o(ac) + V^2{}_o(dc)} \cdot 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assumed lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\dfrac{V^2{}_m}{\pi^2 R_L}}{\dfrac{V^2{}_m}{4R_L}} \cdot 100\% = \frac{4}{\pi^2} \cdot 100\% = 40.6\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\dfrac{V^2{}_m}{2R_L}}{\dfrac{V^2{}_m}{R_L}} \cdot 100\% = 50\% \quad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 10) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 9.

It should be emphasized that Figure 9 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_o with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 9.

MOTOROLA

MR810 thru MR814
MR816 thru MR818

Designers Data Sheet

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free-wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 350 nanoseconds providing high efficiency at frequencies to 100 kHz.

FAST RECOVERY POWER RECTIFIERS

50-1000 VOLTS
1 AMPERE

DESIGNER'S DATA FOR "WORST CASE" CONDITIONS

The Designers Data Sheet permits the design of most circuits entirely from the information presented. Limit curves – representing device characteristic boundaries – are given to facilitate "worst case" design.

MAXIMUM RATINGS

Rating	Symbol	MR810	MR811	MR812	MR813	MR814	MR816	MR817	MR818	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	500	800	1000	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	100	200	300	400	500	800	1000	1200	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	420	560	700	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_A = 75^oC$)	I_O	← 1.0 →								Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions) ($T_A = 75^oC$)	I_{FSM}	← 30 →								Amps
Operating Junction Temperature Range	T_J	← -65 to +150 →								^oC
Storage Temperature Range	T_{stg}	← -65 to +175 →								^oC

THERMAL CHARACTERISTICS

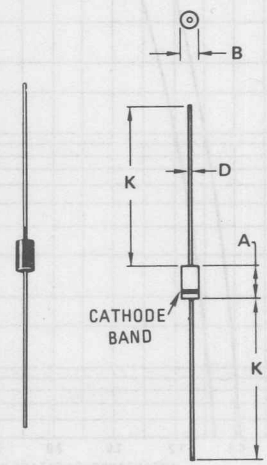
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Typical Primted Circuit Board Mounting)	$R_{\theta JA}$	65	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage ($i_F = 3.14$ Amp, $T_J = 150^oC$)	v_F	–	1.1	1.2	Volts
Forward Voltage ($I_F = 1.0$ Amp, $T_A = 25^oC$)	V_F	–	1.0	1.2	Volts
Reverse Current (rated dc voltage) $T_A = 25^oC$ $T_A = 100^oC$	I_R	– –	1.0 50	10 100	μA

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time ($I_F = 1.0$ Amp to $V_R = 30$ Vdc) (Figure 21) ($I_F = 20$ mA, $I_R = 2.0$ mA, Tektronix S-Plug-In) (Figure 22)	t_{rr}	– –	350 1.5	750 3.0	ns μs
Reverse Recovery Current ($I_F = 1.0$ Amp to $V_R = 30$ Vdc) (Figure 21)	$I_{RM(REC)}$	–	–	3.0	Amp



DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.97	6.60	0.235	0.260
B	2.79	3.05	0.110	0.120
D	0.76	0.86	0.030	0.034
K	27.94	–	1.100	–

CASE 59-04

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded

FINISH: External leads are plated and are readily solderable

POLARITY: Cathode indicated by Polarity band

WEIGHT: 0.4 Grams (Approximately)

FIGURE 1 – FORWARD VOLTAGE

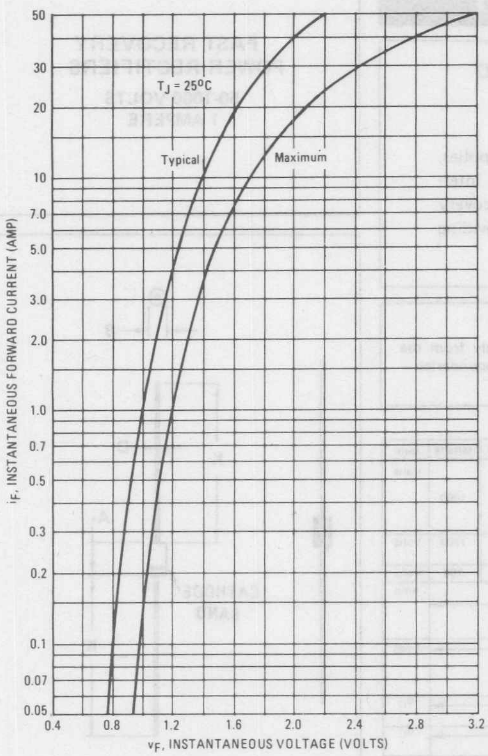


FIGURE 2 – MAXIMUM SURGE CAPABILITY

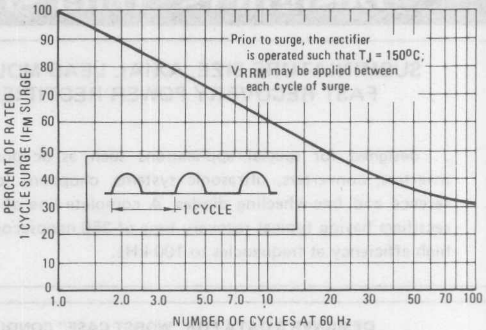


FIGURE 3 – TEMPERATURE COEFFICIENT

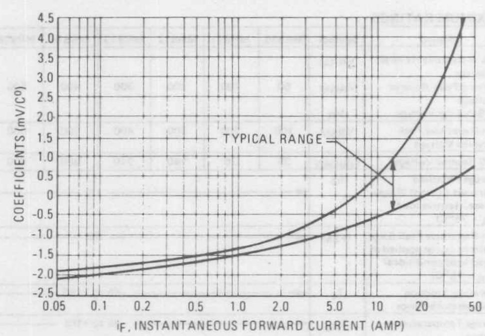


FIGURE 4 – FORWARD POWER DISSIPATION

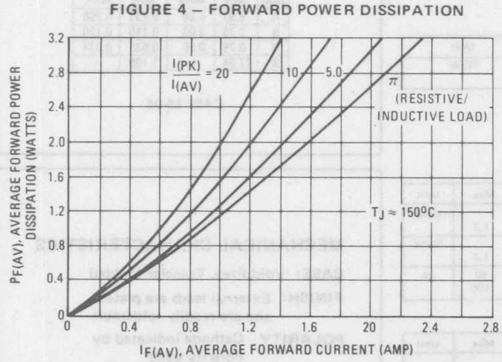
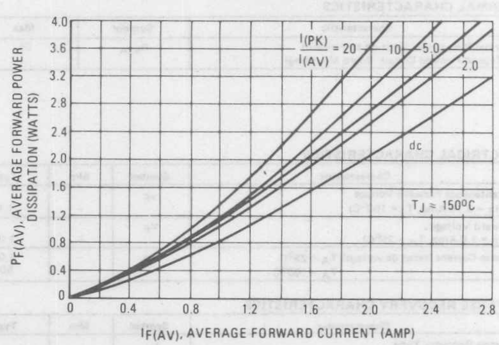


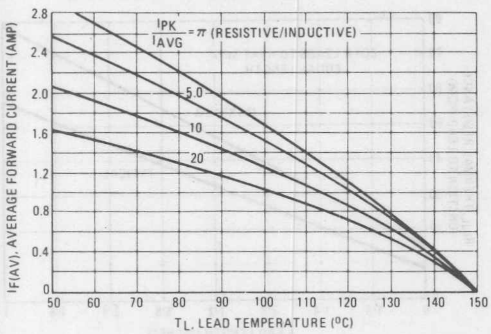
FIGURE 5 – FORWARD POWER DISSIPATION



MAXIMUM CURRENT RATINGS
(SEE NOTES 1 and 2)

SINE WAVE INPUT

FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD



SQUARE WAVE INPUT

FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

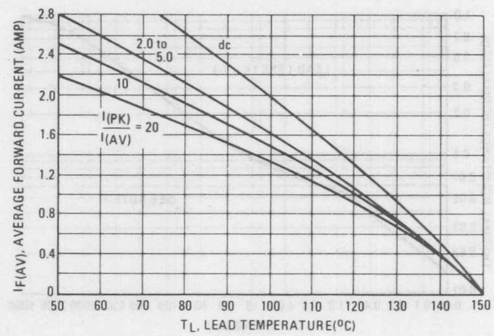


FIGURE 8 – 1/8" LEAD LENGTH, VARIOUS LOADS

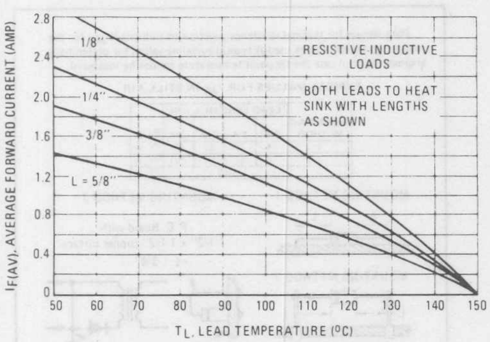


FIGURE 9 – 1/8" LEAD LENGTH, VARIOUS LOADS

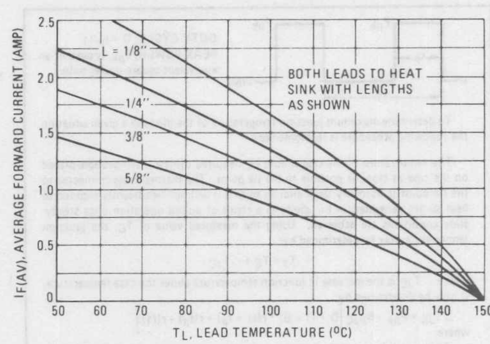


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

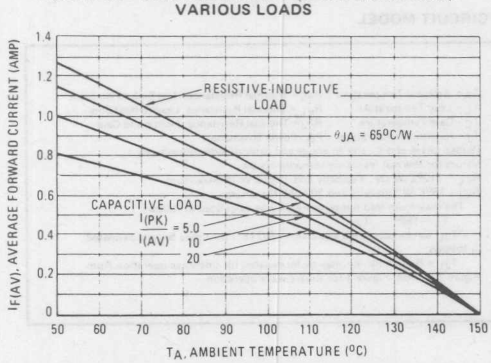


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

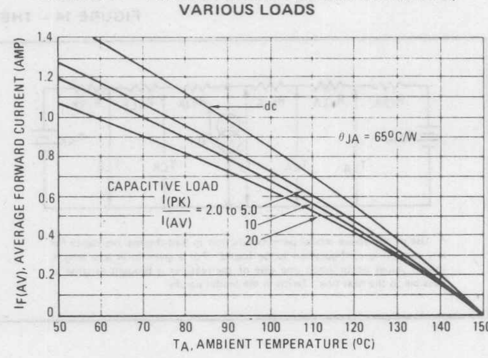


FIGURE 12 – THERMAL RESPONSE

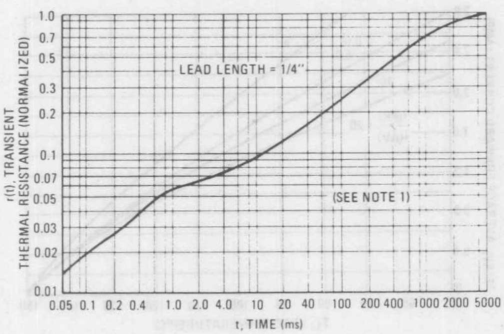
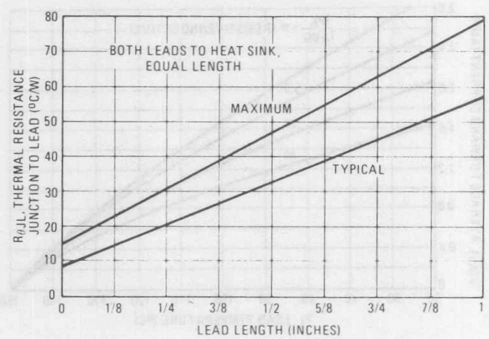
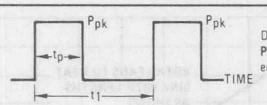


FIGURE 13 – THERMAL RESISTANCE



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC}\left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)\right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 12, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

NOTE 2

Data shown for thermal resistance junction-to-ambient (θ_{JA}) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR θ_{JA} IN STILL AIR

MOUNTING METHOD	LEAD LENGTH, L (IN)				$R_{\theta JA}$
	1/8	1/4	1/2	3/4	
1	65	72	82	92	°C/W
2	74	81	91	101	°C/W
3	40				°C/W

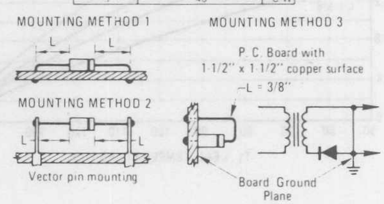
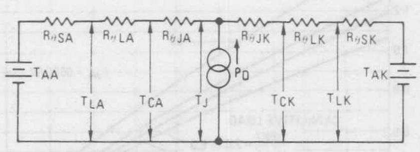


FIGURE 14 – THERMAL CIRCUIT MODEL



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature
T_L = Lead Temperature
T_C = Case Temperature
T_J = Junction Temperature
$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
$R_{\theta J}$ = Thermal Resistance, Junction to Case
P_D = Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.)

Values for thermal resistance components are:

$R_{\theta L}$ = 112°C/W/IN. Typically and 128°C/W/IN Maximum
$R_{\theta J}$ = 18°C/W Typically and 30°C/W Maximum

The maximum lead temperature may be calculated as follows:

$$T_L = 150° - \Delta T_{JL}$$

ΔT_{JL} can be calculated as shown in NOTE 1 or it may be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \bullet P_F$; P_F may be formulated for sine-wave operation from Figure 3 or from Figure 4 for square-wave operation.

TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 15 – FORWARD RECOVERY TIME

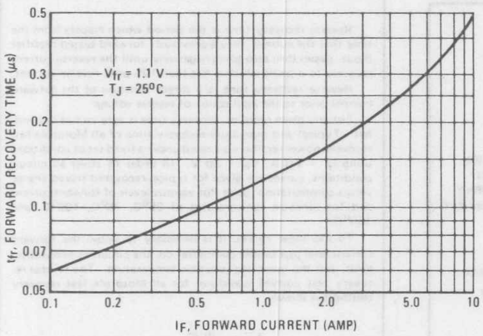
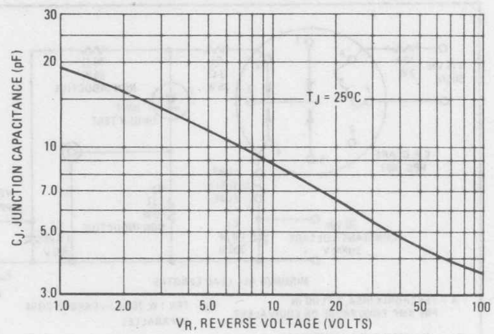


FIGURE 16 – JUNCTION CAPACITANCE



TYPICAL RECOVERED STORED CHARGE DATA
(SEE NOTE 3)

FIGURE 17 – T_J = 25°C

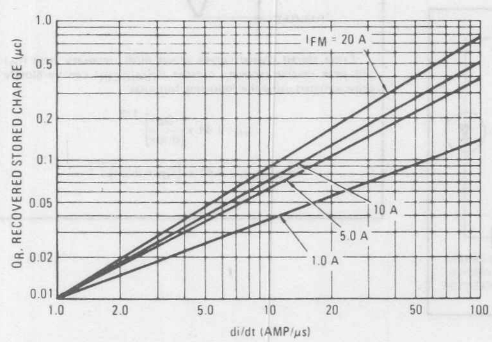


FIGURE 18 – T_J = 75°C

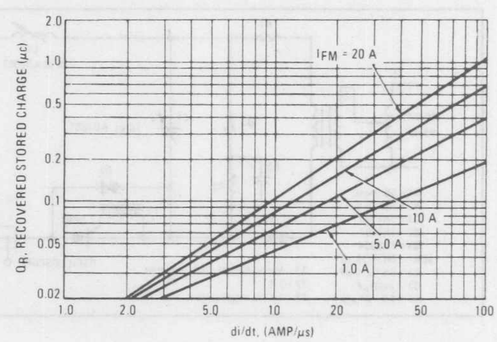


FIGURE 19 – T_J = 100°C

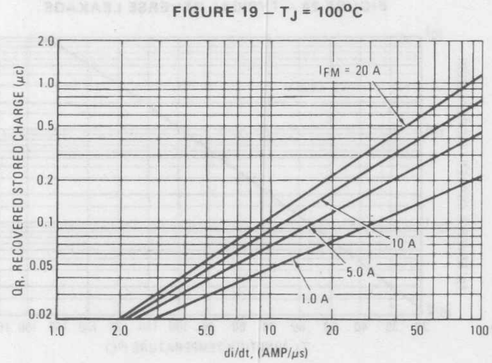


FIGURE 20 – T_J = 150°C

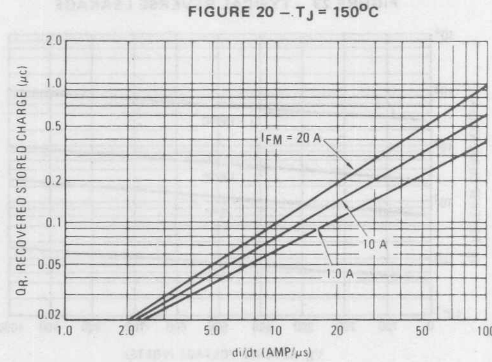


FIGURE 21 – REVERSE RECOVERY CIRCUIT

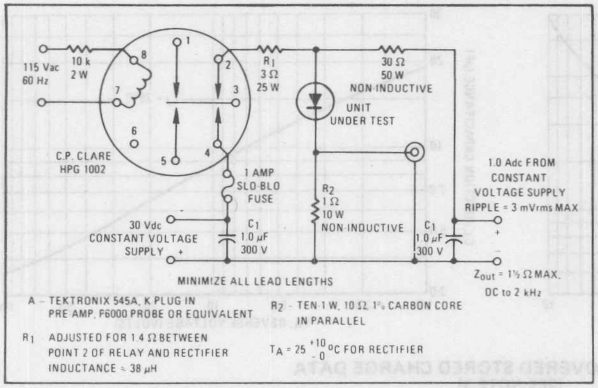
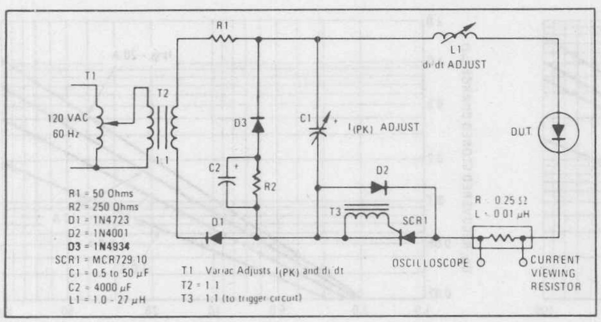


FIGURE 22 – JEDEC REVERSE RECOVERY CIRCUIT



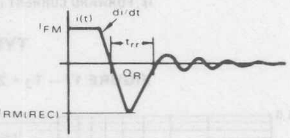
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

FIGURE 23 – TYPICAL REVERSE LEAKAGE

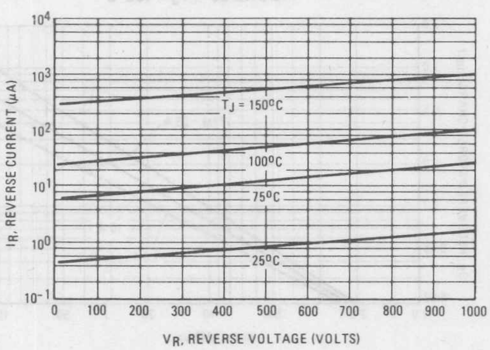
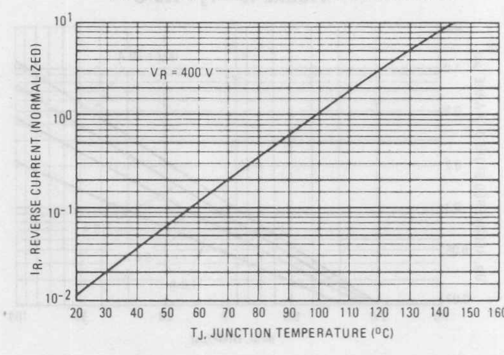


FIGURE 24 – TYPICAL REVERSE LEAKAGE



MOTOROLA

MR820 MR821 MR822 MR824 MR826

Designers Data Sheet

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

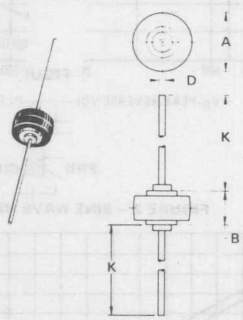
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

FAST RECOVERY POWER RECTIFIERS

50-600 VOLTS
5.0 AMPERES

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.



NOTE:
1. CATHODE SYMBOL ON PKG.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	10.03	10.29	0.395	0.405
B	5.94	6.25	0.234	0.246
D	1.27	1.35	0.050	0.053
K	25.15	25.65	0.990	1.010

CASE 194-01

MAXIMUM RATINGS

Rating	Symbol	MR820	MR821	MR822	MR824	MR826	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_A = 55°C$) (1)	I_O	←		5.0		→	Amp
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions)	I_{FSM}	←		300		→	Amp
Operating and Storage Junction Temperature Range (2)	T_J, T_{stg}	←		-65 to +175		→	°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Recommended Printed Circuit Board Mounting, See Note 6, Page 8)	$R_{\theta JA}$	25	°C/W

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (i_F = 15.7 Amp, T_J = 150°C)	v_F	–	0.75	1.05	Volts
Forward Voltage (I_F = 5.0 Amp, T_J = 25°C)	V_F	–	0.9	1.0	Volts
Maximum Reverse Current, (rated dc voltage) T_J = 25°C T_J = 100°C	I_R	– –	5.0 0.4	25 1.0	μA mA

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 25) (I_{FM} = 15 Amp, di/dt = 25 A/μs, Figure 26)	t_{rr}	– –	150 150	200 300	ns
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 25)	$I_{RM(REC)}$	–	–	2.0	Amp

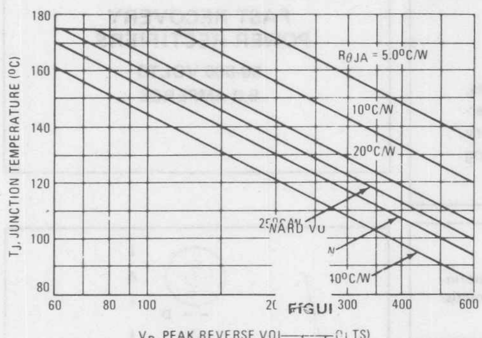
(1) Must be derated for reverse power dissipation. See Note 3
(2) Derate as shown in Figure 1.

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded
FINISH: External Surfaces are Corrosion Resistant
POLARITY: Indicated by Diode Symbol
WEIGHT: 2.5 Grams (Approximately)
MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 350°C, 3/8" from case for 10 s at 5.0 lb. tension.

MAXIMUM CURRENT AND TEMPERATURE RATINGS

FIGURE 1 – MAXIMUM ALLOWABLE JUNCTION TEMPERATURE



NOTE 1
MAXIMUM JUNCTION TEMPERATURE DERATING

When operating this rectifier at junction temperatures over approximately 85°C, reverse power dissipation and the possibility of thermal runaway must be considered. The data of Figure 1 is based upon worst case reverse power and should be used to derate $T_{J(max)}$ from its maximum value of 175°C. See Note 3 for additional information on derating for reverse power dissipation.

When current ratings are computed from $T_{J(max)}$ and reverse power dissipation is also included, ratings vary with reverse voltage as shown on Figures 2 thru 5.

RESISTIVE LOAD RATINGS

PRINTED CIRCUIT BOARD MOUNTING – SEE NOTE 6, PAGE 8

FIGURE 2 – SINE WAVE INPUT

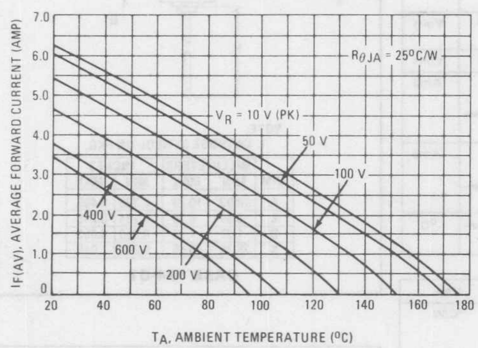


FIGURE 3 – SQUARE WAVE INPUT

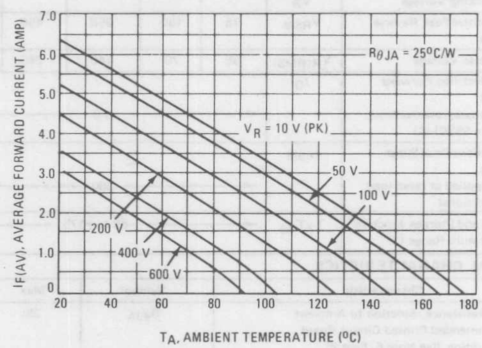


FIGURE 4 – SINE WAVE INPUT

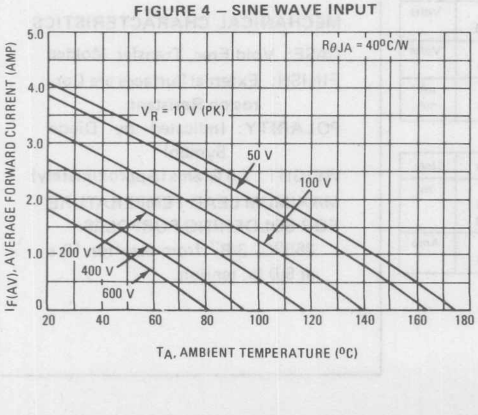
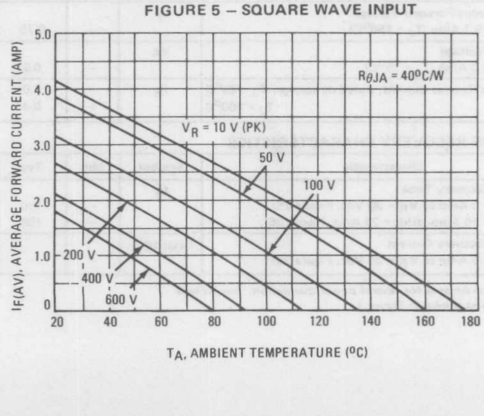


FIGURE 5 – SQUARE WAVE INPUT



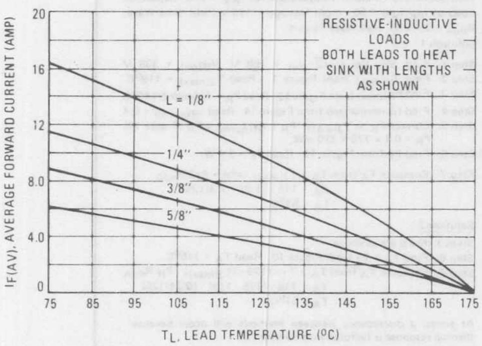
MAXIMUM CURRENT RATINGS

NOTE 2

Current derating data is based upon the thermal response data of Figure 29 and the forward power dissipation data of Figures 19 and 20. Since reverse power dissipation is not considered in Figures 6 thru 11, additional derating for reverse voltage and for junction to ambient thermal resistance must be applied. See Note 3.

SINE WAVE INPUT

FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD



SQUARE WAVE INPUT

FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

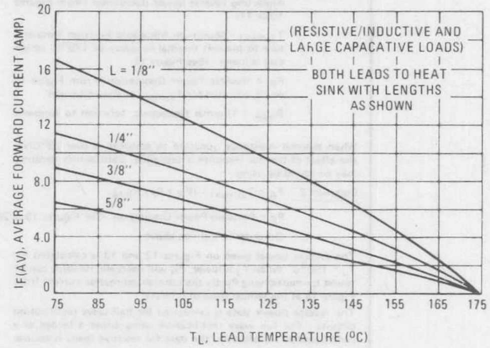


FIGURE 8 – 1/8″ LEAD LENGTH, VARIOUS LOADS

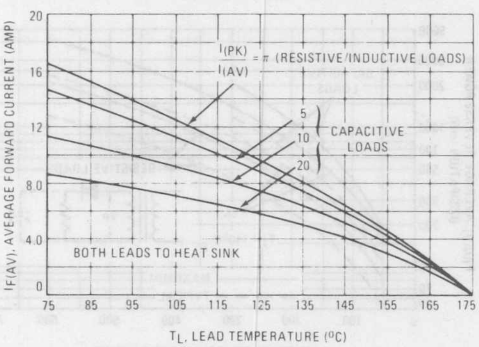


FIGURE 9 – 1/8″ LEAD LENGTH, VARIOUS LOADS

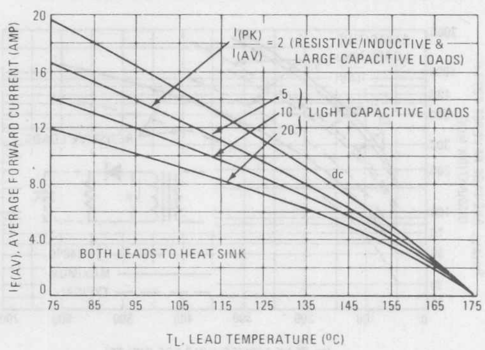


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS

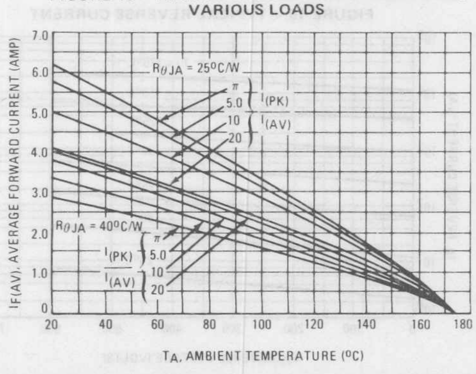
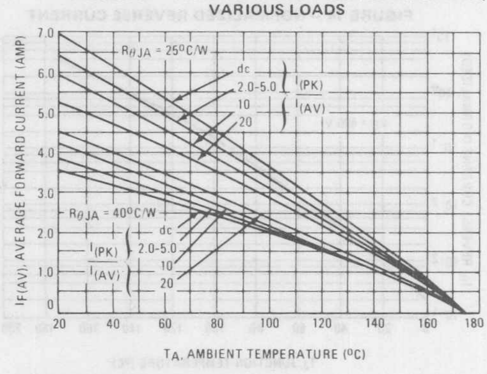


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS



REVERSE POWER DISSIPATION AND CURRENT

NOTE 3
DERATING FOR REVERSE POWER DISSIPATION

In this rectifier, power loss due to reverse current is generally not negligible. For reliable circuit design, the maximum junction temperature must be limited to either 175°C or the temperature which results in thermal runaway. Proper derating may be accomplished by use of equation 1 or equation 2.

Equation 1 $T_A = T_1 - (175 - T_{J(max)}) - P_R R_{\theta JA}$

Where: T_1 = Maximum Allowable Ambient Temperature neglecting reverse power dissipation (from Figures 10 or 11)

$T_{J(max)}$ = Maximum Allowable Junction Temperature to prevent thermal runaway or 175°C, which ever is lower. (See Figure 1).

P_R = Reverse Power Dissipation (From Figure 12 or 13, adjusted for $T_{J(max)}$ as shown below)

$R_{\theta JA}$ = Thermal Resistance, Junction to Ambient.

When thermal resistance, junction to ambient, is over 20°C/W, the effect of thermal response is negligible. Satisfactory derating may be found by using:

Equation 2 $T_A = T_{J(max)} - (P_R + P_F) R_{\theta JA}$

P_F = Forward Power Dissipation (See Figures 19 & 20)

Other terms defined above.

The reverse power given on Figures 12 and 13 is calculated for T_J = 150°C. When T_J is lower, P_R will decrease; its value can be found by multiplying P_R by the normalized reverse current from Figure 14 at the temperature of interest.

The reverse power data is calculated for half wave rectification circuits. For full wave rectification using either a bridge or a center-tapped transformer, the data for resistive loads is equivalent when V_P is the line to line voltage across the rectifiers. For capacitive loads, it is recommended that the dc case on Figure 13 be used, regardless of input waveform, for bridge circuits. For capacitively loaded full wave center-tapped circuits, the 20:1 data of Figure 12 should be used for sine wave inputs and the capacitive load data of Figure 13 should be used for square wave inputs regardless of $I_{(pk)}/I_{(av)}$. For these two cases, V_P is the voltage across one leg of the transformer.

EXAMPLE:

Find Maximum Ambient Temperature for I_{AV} = 2 A, Capacitive Load of I_{PK}/I_{AV} = 20, Input Voltage = 120 V (rms) Sine Wave, $R_{\theta JA}$ = 25°C/W, Half Wave Circuit.

Solution 1:

Step 1: Find V_P: $V_P = \sqrt{2}\, V_{in}$ = 169 V, $V_{R(pk)}$ = 338 V
Step 2: Find $T_{J(max)}$ from Figure 1. Read $T_{J(max)}$ = 119°C.
Step 3: Find $P_{R(max)}$ from Figure 12. Read P_R = 770 mW @ 140°C
Step 4: Find I_R normalized from Figure 14. Read $I_{R(norm)}$ = 0.4
Step 5: Correct P_R to $T_{J(max)}$: $P_R = I_{R(norm)} \times P_R$ (Figure 12)
$P_R = 0.4 \times 770 = 310$ mW.
Step 6: Find P_F from Figure 19. Read P_F = 2.4 W.
Step 7: Compute T_A from $T_A = T_{J(max)} - (P_R + P_F) R_{\theta JA}$
$T_A = 119 - (0.31 + 2.4)(25)$
T_A = 51°C

Solution 2:

Steps 1 thru 5 are as above.
Step 6: Find $T_A = T_1$ from Figure 10. Read T_A = 115°C.
Step 7: Compute T_A from $T_A = T_1 - (175 - T_{J(max)}) - P_R R_{\theta JA}$
$T_A = 115 - (175 - 119) - (0.31)(25)$
T_A = 51°C

At times, a discrepancy between methods will occur because thermal response is factored into Solution 2.

FIGURE 12 – SINE WAVE INPUT DISSIPATION

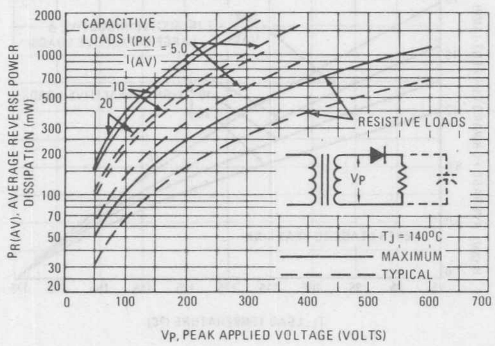


FIGURE 13 – SQUARE WAVE INPUT DISSIPATION

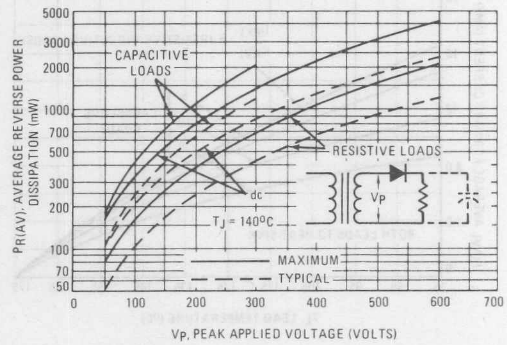


FIGURE 14 – NORMALIZED REVERSE CURRENT

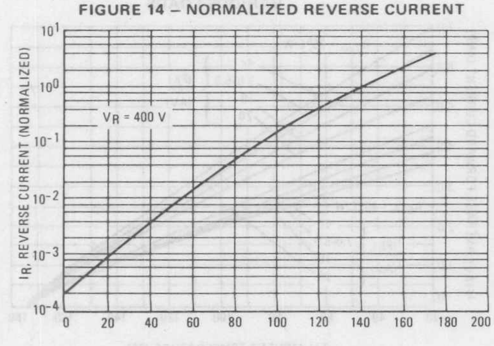
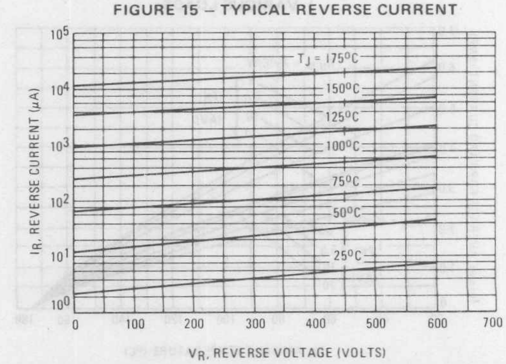


FIGURE 15 – TYPICAL REVERSE CURRENT



STATIC CHARACTERISTICS

FIGURE 16 – FORWARD VOLTAGE

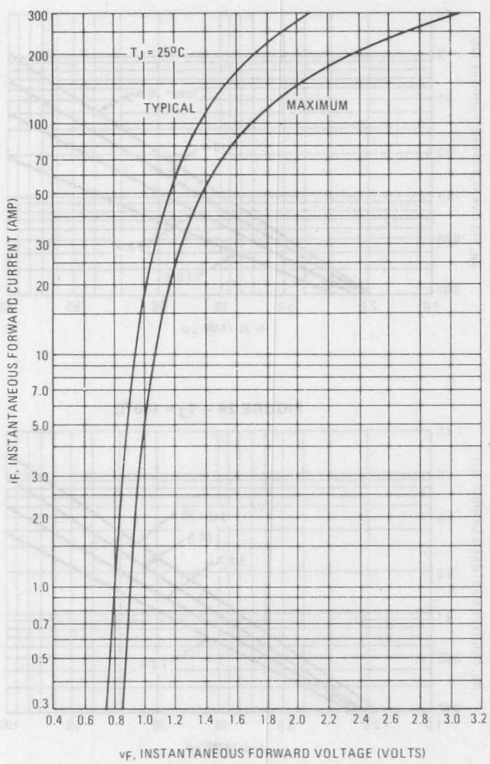


FIGURE 17 – MAXIMUM SURGE CAPABILITY

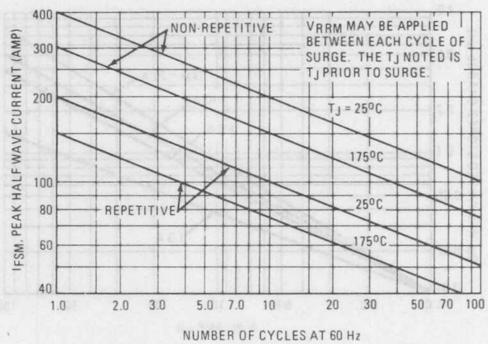
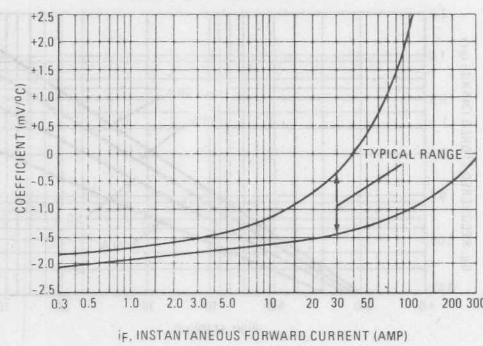


FIGURE 18 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT



MAXIMUM FORWARD POWER DISSIPATION

FIGURE 19 – SINE WAVE INPUT

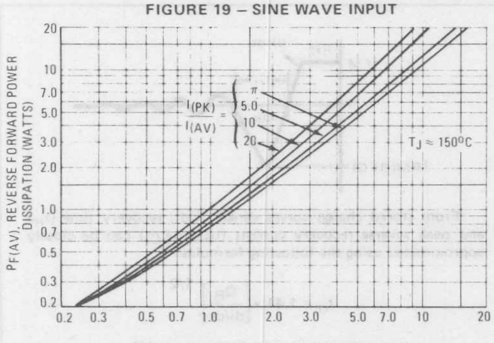
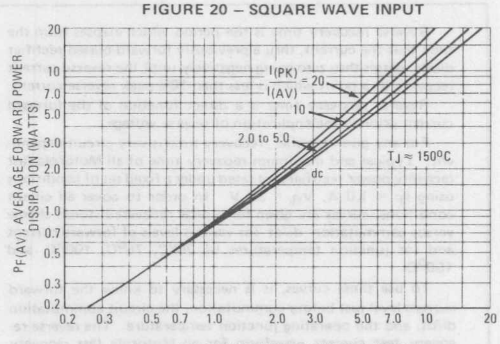


FIGURE 20 – SQUARE WAVE INPUT



TYPICAL RECOVERED STORED CHARGE DATA
(See Note 4)

FIGURE 21 – T_J = 25°C

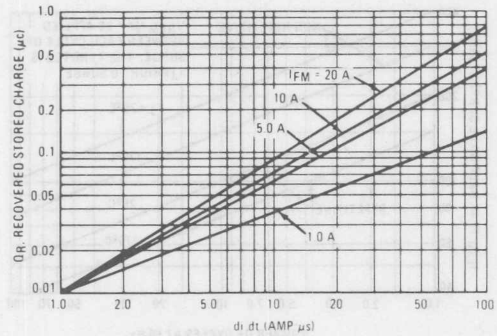


FIGURE 22 – T_J = 75°C

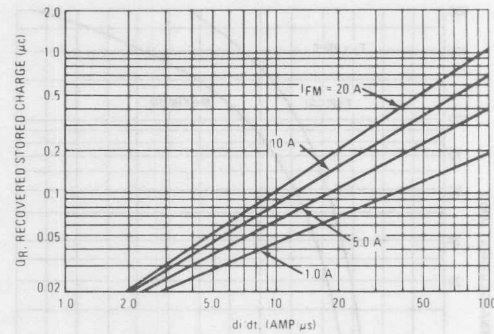


FIGURE 23 – T_J = 100°C

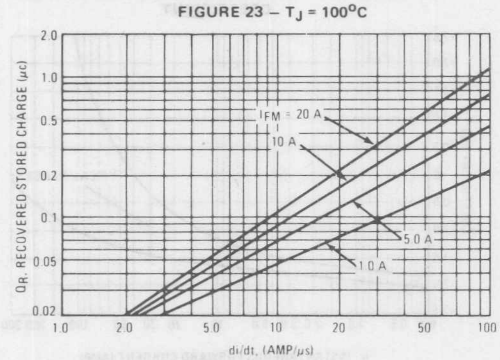
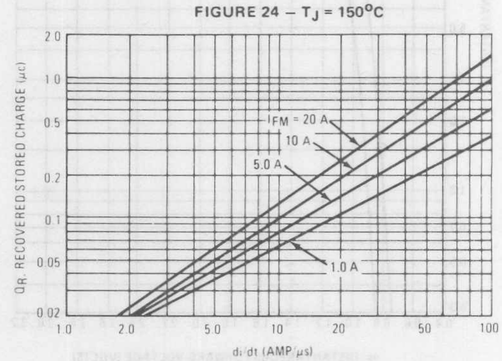


FIGURE 24 – T_J = 150°C



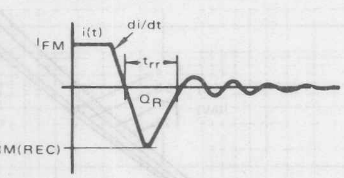
NOTE 4

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using $I_F \approx 1.0$ A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

DYNAMIC CHARACTERISTICS

FIGURE 25 – REVERSE RECOVERY CIRCUIT

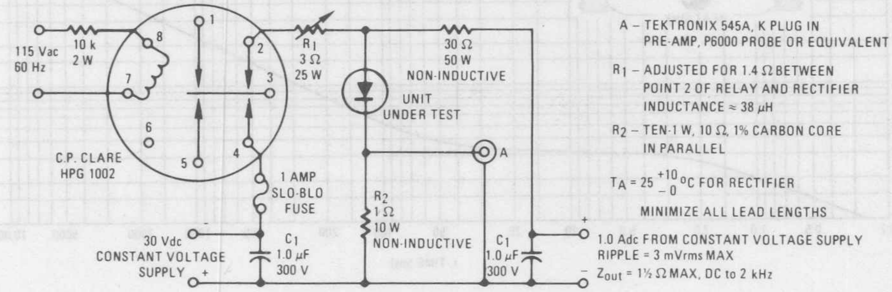


FIGURE 26 – JEDEC REVERSE RECOVERY CIRCUIT

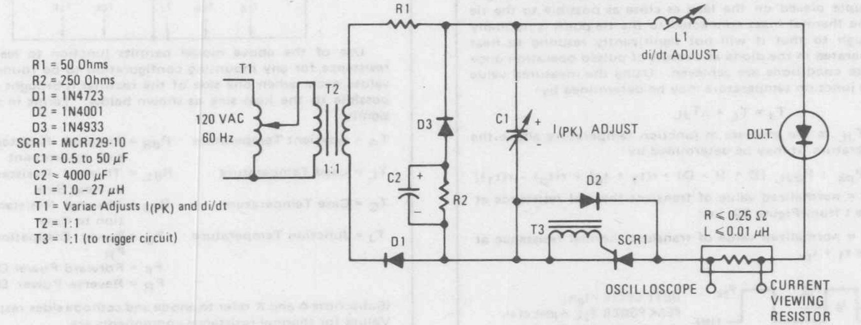


FIGURE 27 – FORWARD RECOVERY TIME

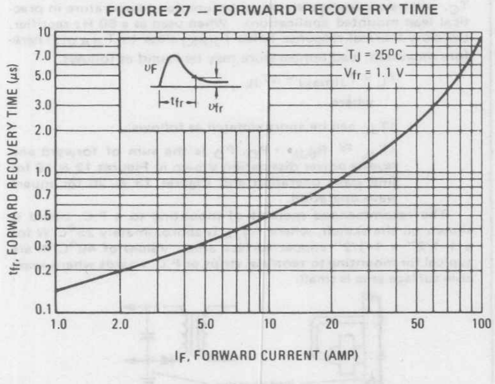
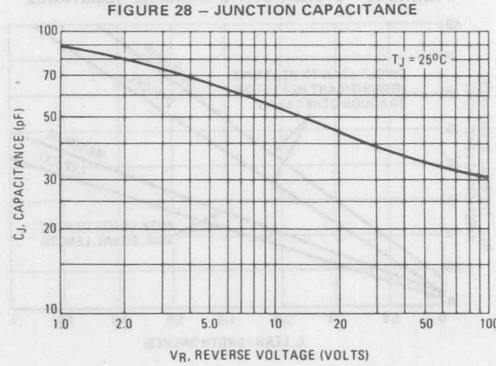
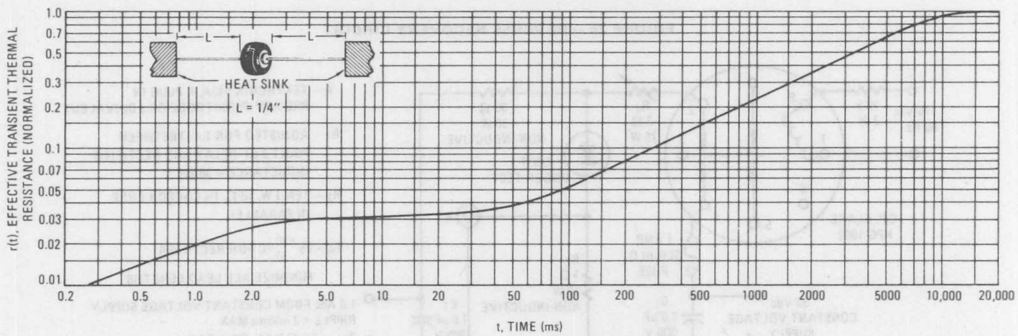


FIGURE 28 – JUNCTION CAPACITANCE



THERMAL CHARACTERISTICS

FIGURE 29 – THERMAL RESPONSE



NOTE 5

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

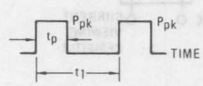
$$T_J = T_L + \Delta T_{JL}$$

where ΔT_{JL} is the increase in junction temperature above the lead temperature. It may be determined by:

$$\Delta T_{JL} = P_{pk} \cdot R_{\theta JL} \, [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

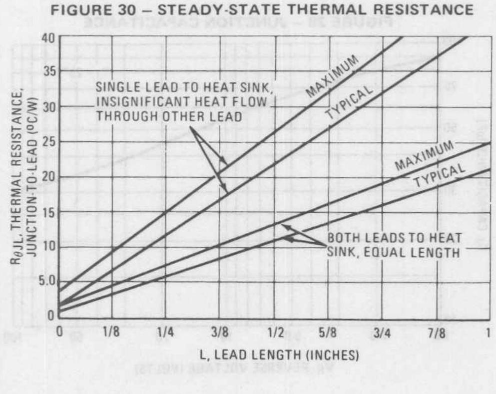
where $r(t)$ = normalized value of transient thermal resistance at time t from Figure 29, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

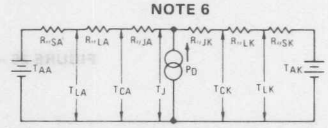


DUTY CYCLE = t_p/t_1
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

FIGURE 30 – STEADY-STATE THERMAL RESISTANCE



NOTE 6



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. Lowest values occur when one side of the rectifier is brought as close as possible to the heat sink as shown below. Terms in the model signify:

T_A = Ambient Temperature	$R_{\theta S}$ = Thermal Resistance, Heat sink to Ambient
T_L = Lead Temperature	$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
T_C = Case Temperature	$R_{\theta J}$ = Thermal Resistance, Junction to Case
T_J = Junction Temperature	P_D = Power Dissipation = $P_F + P_R$
	P_F = Forward Power Dissipation
	P_R = Reverse Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively) Values for thermal resistance components are:

$R_{\theta L}$ = 40°C/W/IN. Typically and 44°C/W/IN Maximum.
$R_{\theta J}$ = 2°C/W Typically and 4°C/W Maximum.

Since $R_{\theta J}$ is so low, measurements of the case temperature, T_C, will be approximately equal to junction temperature in practical lead mounted applications. When used as a 60 Hz rectifier, the slow thermal response holds $T_{J(PK)}$ close to $T_{J(AV)}$. Therefore maximum lead temperature may be found as follows:

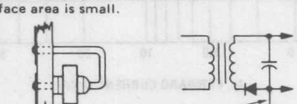
$$T_L = T_{J(max)} - \Delta T_{JL}$$

where

ΔT_{JL} can be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \cdot P_D$; P_D is the sum of forward and reverse power dissipation shown in Figures 12 & 19 for sine wave operation and Figures 13 & 20 for square wave operation.

The recommended method of mounting to a P.C. board is shown on the sketch, where $R_{\theta JA}$ is approximately 25°C/W for a 1-1/2" x 1-1/2" copper surface area. Values of 40°C/W are typical for mounting to terminal strips or P.C. boards where available surface area is small.



Recommended mounting for half wave circuit

MOTOROLA

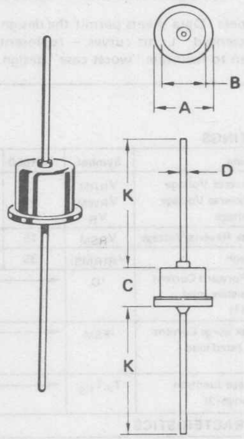
MR830 MR831 MR832 MR834 MR836

HERMETICALLY SEALED, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

FAST RECOVERY POWER RECTIFIERS

50-600 VOLTS
3 AMPERES



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	–	11.43	–	0.450
B	–	8.89	–	0.350
C	–	7.62	–	0.300
D	1.17	1.42	0.046	0.056
K	24.89	–	0.980	–

CASE 60-1

MAXIMUM RATINGS

Rating	Symbol	MR830	MR831	MR832	MR834	MR836	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^oC$)	I_O	← 3.0 →					Amps
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	← 100 →					Amps
Operating Junction Temperature Range	T_J	← -65 to +150 →					^oC
Storage Temperature Range	T_{stg}	← -65 to +175 →					^oC

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Max	Unit
Forward Voltage ($I_F = 3.0$ Adc, $T_A = 25^oC$)	V_F	–	1.1	Volts
Reverse Current (rated DC Voltage) $T_A = 25^oC$	I_R	–	0.05	mA
$T_A = 100^oC$		–	1.5	

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time ($I_F = 1.0$ Amp to $V_R = 30$ Vdc)	t_{rr}	–	150	200	ns
($I_{FM} = 15$ Amp, di/dt = 25 A/μs)		–	150	300	ns
Reverse Recovery Current ($I_F = 1.0$ Amp to $V_R = 30$ Vdc)	$I_{RM(REC)}$	–	–	2.0	Amp

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and leads readily solderable

POLARITY: Cathode to Case

WEIGHT: 2.4 Grams (Approximately)

MOTOROLA

MR850 MR851 MR852 MR854 MR856

Designers Data Sheet

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

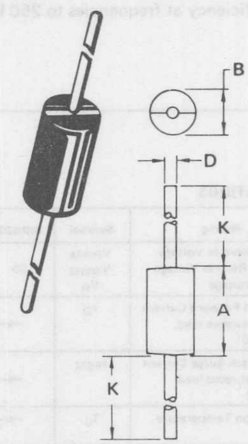
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

FAST RECOVERY POWER RECTIFIERS

50-600 VOLTS
3 AMPERE



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	9.65	0.370	0.380
B	4.83	5.33	0.190	0.210
D	1.22	1.32	0.048	0.052
K	26.97	27.23	1.062	1.072

CASE 267-01

MAXIMUM RATINGS

Rating	Symbol	MR850	MR851	MR852	MR854	MR856	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	Volts
Average Rectified Forward Current (Single phase resistive load, $T_A = 90^oC$) (1)	I_O	←		3.0		→	Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	←		100 (one cycle)		→	Amp
Operating and Storage Junction Temperature Range (2)	T_J, T_{stg}	←		-65 to +175		→	^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient (Recommended Printed Circuit Board Mouting, See Note 6, Page 8)	$R_{\theta JA}$	28	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (i_F = 9.4 Amp, $T_J = 175^oC$)	v_F	–	0.9	1.1	Volts
Forward Voltage (I_F = 3.0 Amp, $T_J = 25^oC$)	V_F	–	1.04	1.25	Volts
Reverse Current (rated dc voltage) $T_J = 25^oC$	I_R	–	2.0	10	μA
$T_J = 100^oC$ MR850		–	–	150	
MR851		–	60	150	
MR852		–	–	200	
MR854		–	–	250	
MR856		–	100	300	

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time	t_{rr}				ns
(I_F = 1.0 Amp to V_R = 30 Vdc, Figure 25)		–	150	200	
(I_F = 15 Amp, di/dt = 10 A/μs, Figure 26)		–	200	300	
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 25)	$I_{RM(REC)}$	–	–	2.0	Amp

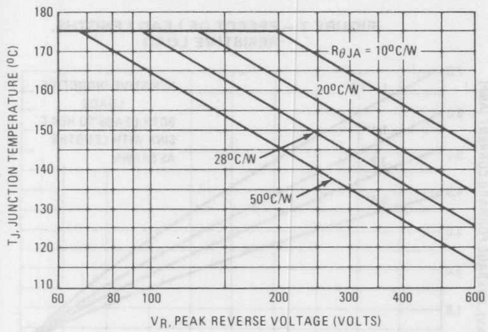
(1) Must be derated for reverse power dissipation. See Note 2, Page 4.
(2) Derate as shown in Figure 1

MECHANICAL CHARACTERISTICS

Case: Void Free, Transfer Molded
Finish: External Leads are Plated, Leads are readily Solderable
Polarity: Cathode Indicated by Polarity Band
Weight: 1.1 Grams (Approximately)
Maximum Lead Temperature for Soldering Purposes:
300°C, 1/8" from case for 10 s at 5.0 lb. tension

MAXIMUM CURRENT AND TEMPERATURE RATINGS

FIGURE 1 – MAXIMUM ALLOWABLE JUNCTION TEMPERATURE



NOTE 1
MAXIMUM JUNCTION TEMPERATURE DERATING

When operating this rectifier at junction temperatures over 120°C, reverse power dissipation and the possibility of thermal runaway must be considered. The data of Figure 1 is based upon worst case reverse power and should be used to derate $T_{J(max)}$ from its maximum value of 175°C. See Note 2 for additional information on derating for reverse power dissipation.

When current ratings are computed from $T_{J(max)}$ and reverse power dissipation is also included, ratings vary with reverse voltage as shown on Figures 2 thru 5.

RESISTIVE LOAD RATINGS

Printed Circuit Board Mounting – See Note 6, Page 8

FIGURE 2 – SINE WAVE INPUT

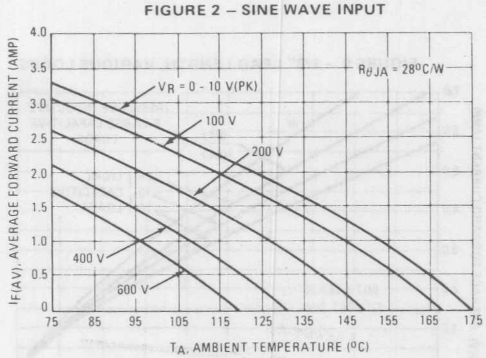


FIGURE 3 – SQUARE WAVE INPUT

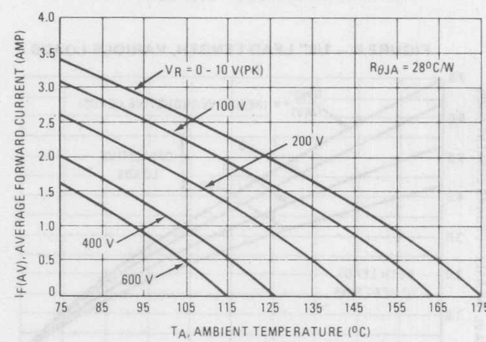


FIGURE 4 – SINE WAVE INPUT

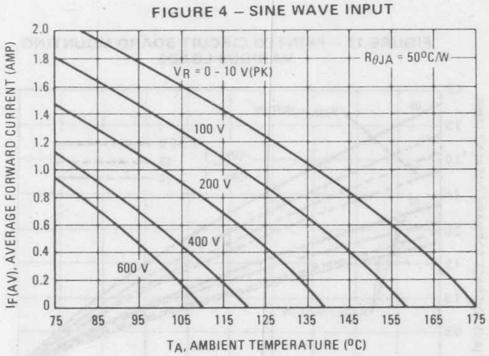
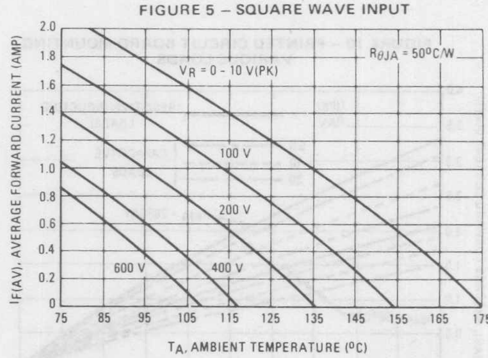


FIGURE 5 – SQUARE WAVE INPUT



MAXIMUM CURRENT RATINGS

Current derating data is based upon the thermal response data of Figure 29 and the forward power dissipation data of Figures 19 and 20. Since reverse power dissipation is not considered in Figures 6 thru 11, additional derating for reverse voltage and for junction to ambient thermal resistance must be applied. See Note 2.

SINE WAVE INPUTS

FIGURE 6 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

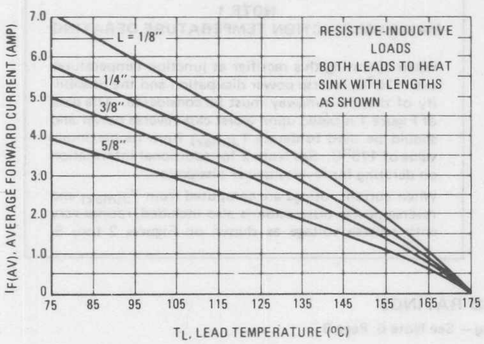


FIGURE 8 – 1/8" LEAD LENGTH, VARIOUS LOADS

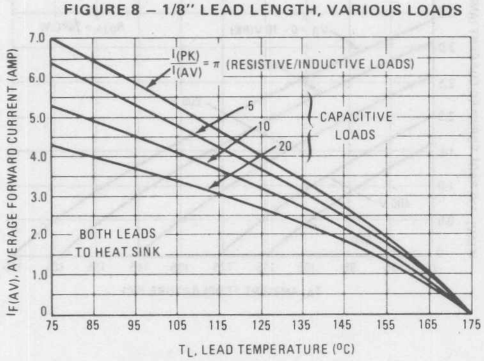
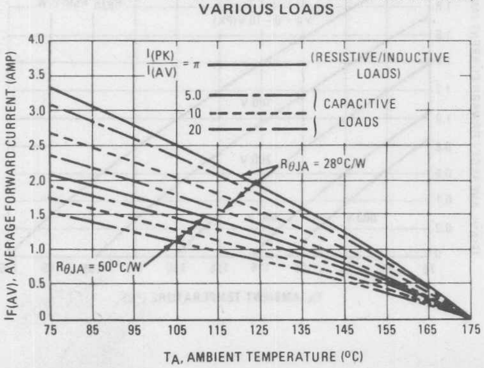


FIGURE 10 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS



SQUARE WAVE INPUTS

FIGURE 7 – EFFECT OF LEAD LENGTHS, RESISTIVE LOAD

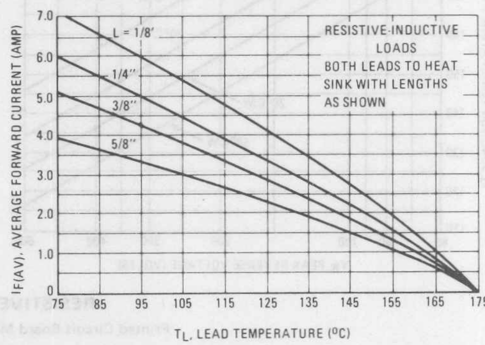


FIGURE 9 – 1/8" LEAD LENGTH, VARIOUS LOADS

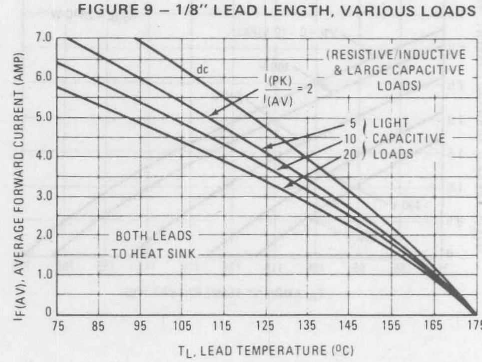
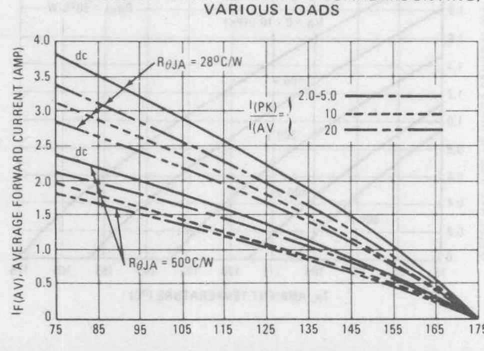


FIGURE 11 – PRINTED CIRCUIT BOARD MOUNTING, VARIOUS LOADS



REVERSE POWER DISSIPATION AND CURRENT

NOTE 2
DERATING FOR REVERSE POWER DISSIPATION

In this rectifier, power loss due to reverse current is generally not negligible. For reliable circuit design, the maximum junction temperature must be limited to either 175°C or the temperature which results in thermal runaway. Proper derating may be accomplished by use of equation 1 or equation 2.

Equation 1 $T_A = T_1 - (175 - T_{J(max)}) - P_R R_{\theta JA}$

Where: T_1 = Maximum Allowable Ambient Temperature neglecting reverse power dissipation (from Figures 10 or 11)

$T_{J(max)}$ = Maximum Allowable Junction Temperature to prevent thermal runaway or 175°C, which ever is lower. (See Figure 1).

P_R = Reverse Power Dissipation (From Figure 12 or 13, adjusted for $T_{J(max)}$ as shown below)

$R_{\theta JA}$ = Thermal Resistance, Junction to Ambient.

When thermal resistance, junction to ambient, is over 20°C/W, the effect of thermal response is negligible. Satisfactory derating may be found by using:

Equation 2 $T_A = T_{J(max)} - (P_R + P_F) R_{\theta JA}$

P_F = Forward Power Dissipation (See Figures 19 & 20)

Other terms defined above.

The reverse power given on Figures 12 and 13 is calculated for T_J = 150°C. When T_J is lower, P_R will decrease; its value can be found by multiplying P_R by the normalized reverse current from Figure 14 at the temperature of interest.

The reverse power data is calculated for half wave rectification circuits. For full wave rectification using either a bridge or a center-tapped transformer, the data for resistive loads is equivalent when V_P is the line to line voltage across the rectifiers. For capacitive loads, it is recommended that the dc case on Figure 13 be used, regardless of input waveform, for bridge circuits. For capacitively loaded full wave center-tapped circuits, the 20:1 data of Figure 12 should be used for sine wave inputs and the capacitive load data of Figure 13 should be used for square wave inputs regardless of $I_{(pk)}/I_{(av)}$. For these two cases, V_P is the voltage across one leg of the transformer.

Example 1 Find maximum ambient temperature for I_{AV} = 2 A, capacitive load of I_{PK}/I_{AV} = 20, Input Voltage = 60 V (rms), sine wave, $R_{\theta JA}$ = 28°C/W, half wave circuit.

Solution 1 (using Equation 1)

Step 1: Find V_P; $V_P = \sqrt{2}\, V_{in}$ = 85 V, $V_{R(pk)}$ = 170

Step 2: Find $T_{J(max)}$ from Figure 1. Read $T_{J(max)}$ = 157°C

Step 3: Find $P_{R(max)}$ from Figure 12. Read P_R = 360 mW @ 150°C

Step 4: Find I_R normalized from Figure 14. Read $I_{R(norm)}$ = 1.5

Step 5: Correct P_R to $T_{J(max)}$. $P_R = I_{R(norm)} \times P_R$ (Figure 12) P_R = 1.5 x 360 = 540 mW

Step 6: Find $T_A = T_1$ from Figure 10. Read T_1 = 94°C

Step 7: Compute T_A from $T_A = T_1 - (175 - T_{J(max)}) - P_R R_{\theta JA}$
T_A = 94 - (175 - 157) - (0.54) (28)
T_A = 61°C

Solution 2 (using Equation 2)

Steps 1 thru 5 are as Solution 1

Step 6: Find P_F from Figure 19. Read P_F = 3.0 W

Step 7: Compute T_A from $T_A = T_{J(max)} - (P_R + P_F) R_{\theta JA}$
T_A = 157 - (0.54 + 3) 28
T_A = 58°C

The discrepancy occurs because thermal response is factored into solution 1, and advantage is taken of the cooling time after the power pulse and before reverse voltage achieves its maximum. 61°C is a satisfactory ambient temperature.

FIGURE 12 – REVERSE POWER DISSIPATION, SINE WAVE

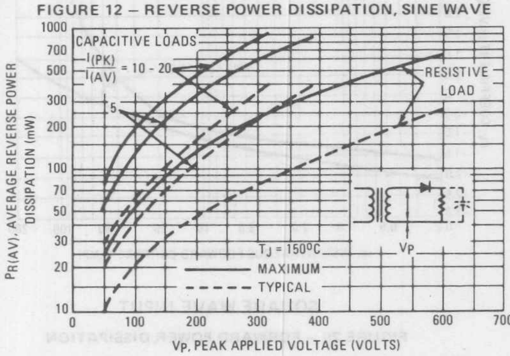


FIGURE 13 – REVERSE POWER DISSIPATION, SQUARE WAVE

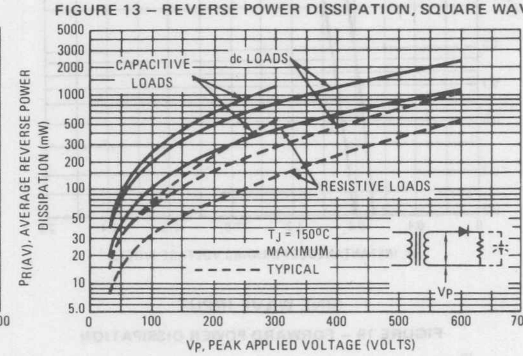


FIGURE 14 – NORMALIZED REVERSE CURRENT

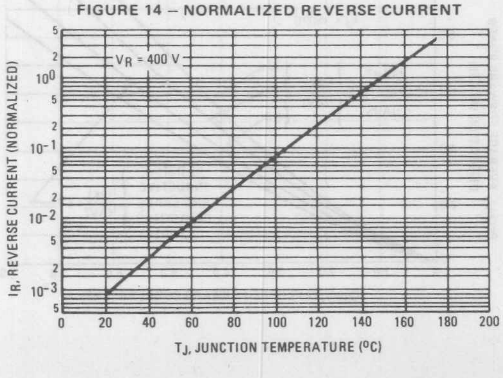
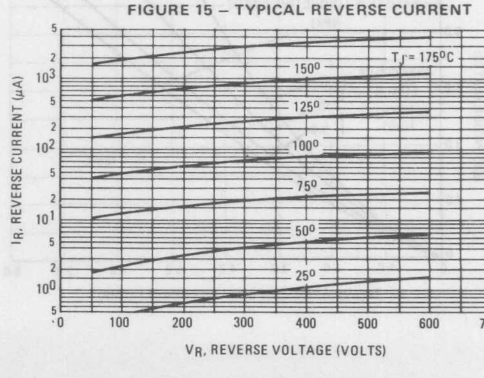


FIGURE 15 – TYPICAL REVERSE CURRENT



STATIC CHARACTERISTICS

FIGURE 16 – FORWARD VOLTAGE

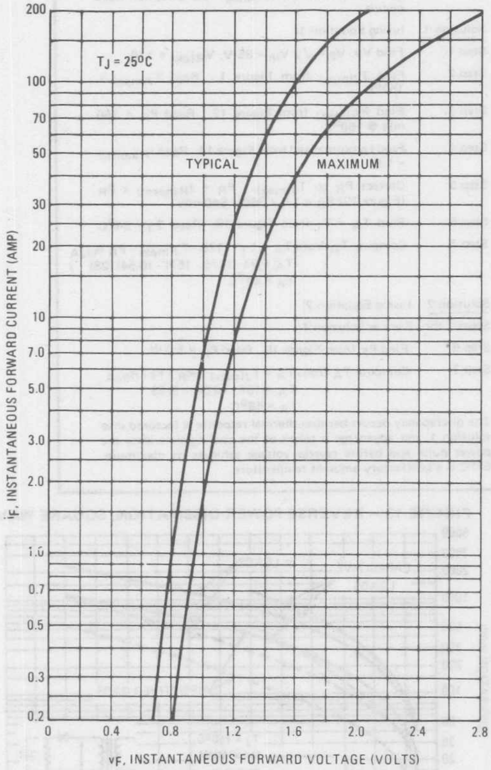


FIGURE 17 – MAXIMUM SURGE CAPABILITY

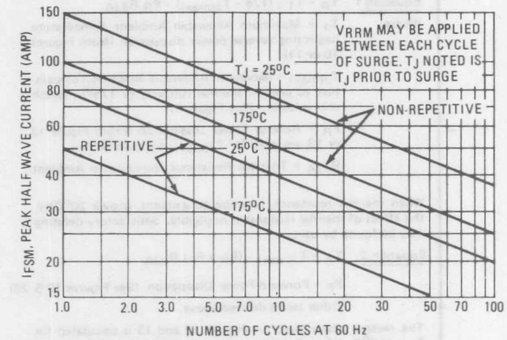
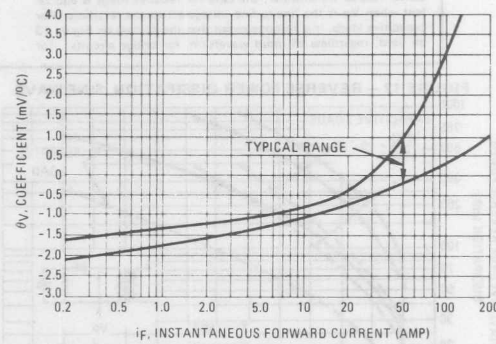
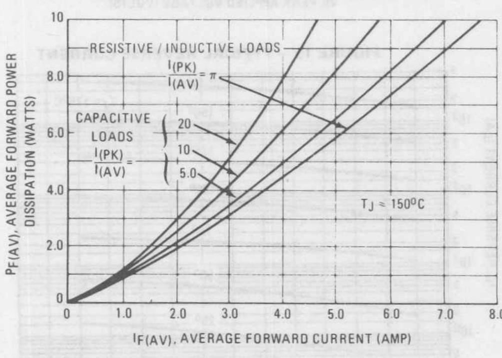


FIGURE 18 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT



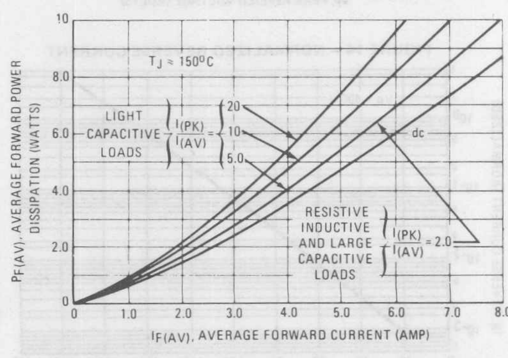
SINE WAVE INPUT

FIGURE 19 – FORWARD POWER DISSIPATION



SQUARE WAVE INPUT

FIGURE 20 – FORWARD POWER DISSIPATION



TYPICAL RECOVERED STORED CHARAGE DATA

(See Note 3)

FIGURE 21 – $T_J = 25^oC$

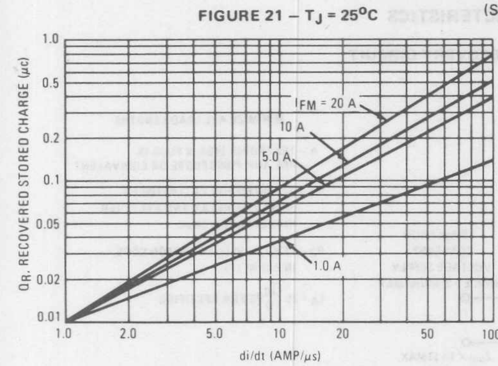


FIGURE 22 – $T_J = 75^oC$

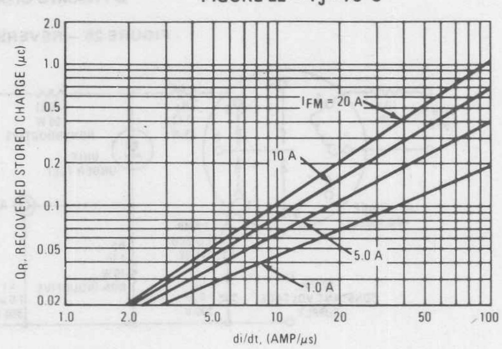


FIGURE 23 – $T_J = 100^oC$

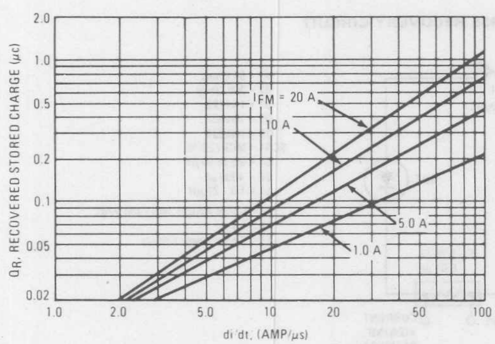
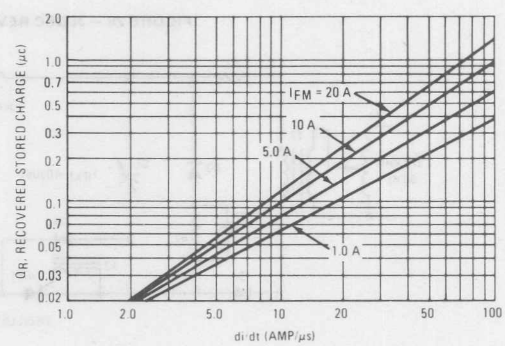


FIGURE 24 – $T_J = 150^oC$



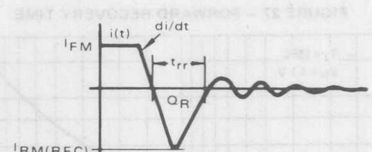
NOTE 3

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

DYNAMIC CHARACTERISTICS

FIGURE 25 – REVERSE RECOVERY CIRCUIT

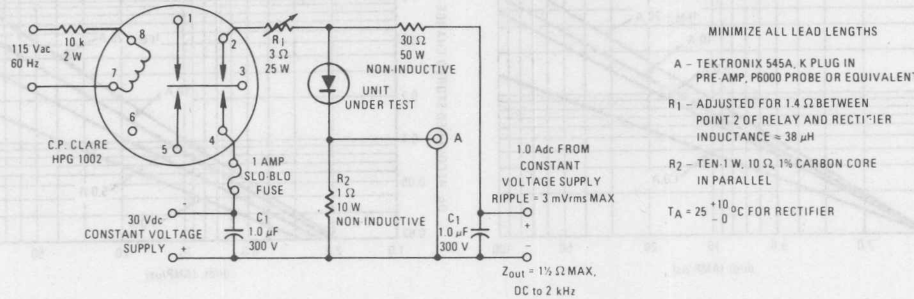


FIGURE 26 – JEDEC REVERSE RECOVERY CIRCUIT

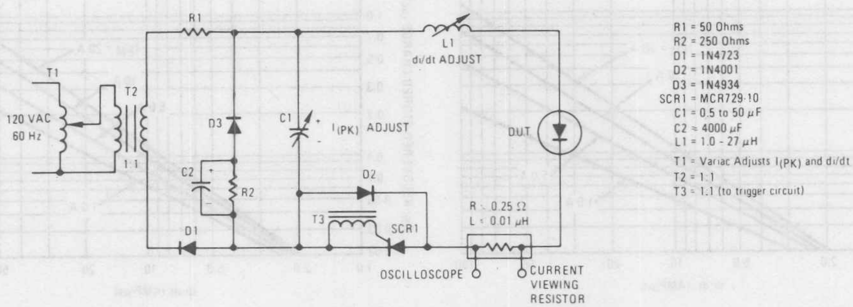


FIGURE 27 – FORWARD RECOVERY TIME

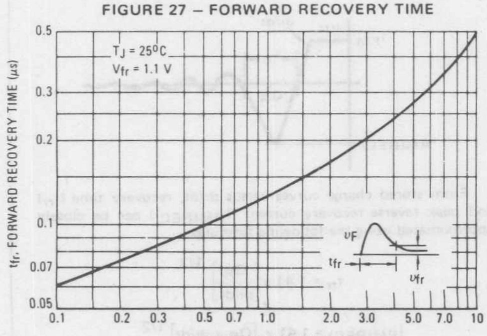


FIGURE 28 – JUNCTION CAPACITANCE

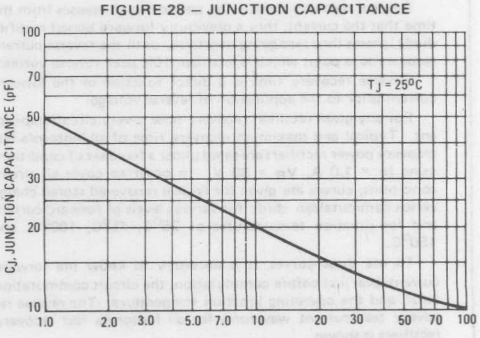


FIGURE 29 – THERMAL RESPONSE

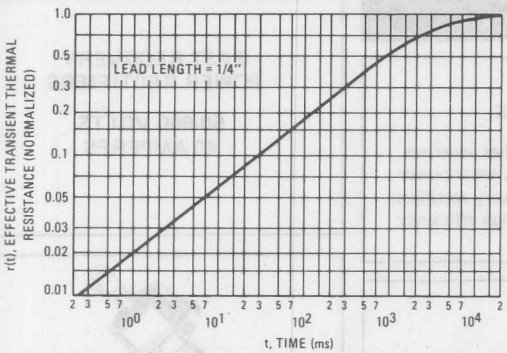
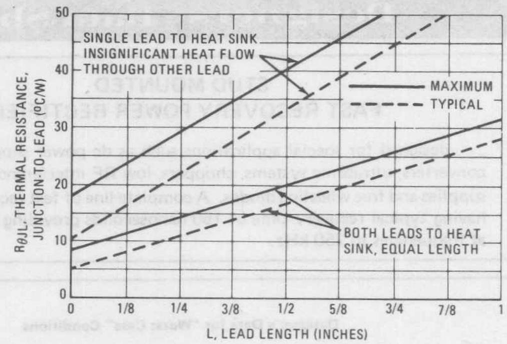


FIGURE 30 – STEADY-STATE THERMAL RESISTANCE



NOTE 4

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

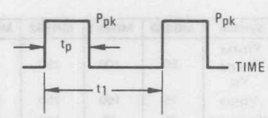
$$T_J = T_L + \Delta T_{JL}$$

where ΔT_{JL} is the increase in junction temperature above the lead temperature. It may be determined by:

$$\Delta T_{JL} = P_{pk} \cdot R_{\theta JL} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)\right]$$

where $r(t)$ = normalized value of transient thermal resistance at time t from Figure 29, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.



DUTY CYCLE = t_p/t_1
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

NOTE 5

Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature	$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
T_L = Lead Temperature	$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
T_C = Case Temperature	$R_{\theta J}$ = Thermal Resistance, Junction to Case
T_J = Junction Temperature	P_D = Total Power Dissipation = $P_F + P_R$
	P_F = Forward Power Dissipation
	P_R = Reverse Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.) Values for thermal resistance components are:

$R_{\theta L}$ = 46°C/W/IN. Typically and 48°C/W/IN Maximum.
$R_{\theta J}$ = 10°C/W Typically and 16°C/W Maximum.

The maximum lead temperature may be found as follows:

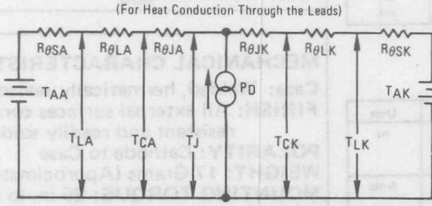
$$T_L = T_{J(max)} - \Delta T_{JL}$$

where

ΔT_{JL} can be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \cdot P_D$. P_D is the sum of forward and reverse power dissipation shown in Figures 2 and 4 for sine wave operation and Figures 3 and 5 for square wave operation.

THERMAL CIRCUIT MODEL
(For Heat Conduction Through the Leads)



NOTE 6

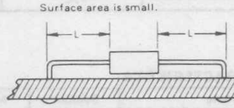
Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

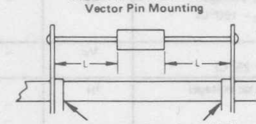
MOUNTING METHOD	LEAD LENGTH, L (IN) 1/8	1/4	1/2	3/4	$R_{\theta JA}$
1	50	51	53	55	°C/W
2	58	59	61	63	°C/W
3	28				°C/W

MOUNTING METHOD 1

P.C. Board Where Available Copper Surface area is small.



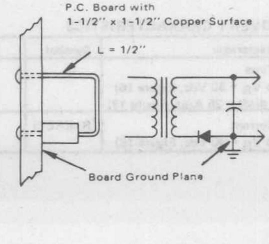
MOUNTING METHOD 2
Vector Pin Mounting



Vector Push-In Terminals T-28

MOUNTING METHOD 3

P.C. Board with 1-1/2″ x 1-1/2″ Copper Surface



Board Ground Plane

MOTOROLA

MR860 MR861 MR862 MR864 MR866

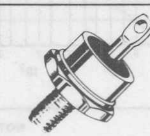
Designers Data Sheet

STUD MOUNTED FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference, sonar power supplies and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

FAST RECOVERY POWER RECTIFIERS

50-600 VOLTS
40 AMPERES



Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

MAXIMUM RATINGS

Rating	Symbol	MR860	MR861	MR862	MR864	MR866	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^oC$)	I_O	←		40		→	Amps
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	←		350		→	Amps
Operating Junction Temperature Range	T_J	←		-65 to +160		→	^oC
Storage Temperature Range	T_{stg}	←		-65 to +175		→	^oC

THERMAL CHARACTERISTICS

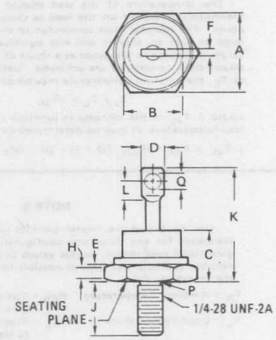
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	0.85	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (i_F = 125 Amp, $T_J = 150^oC$)	v_F	–	1.3	1.6	Volts
Forward Voltage (I_F = 40 Amp, $T_C = 25^oC$)	V_F	–	1.0	1.4	Volts
Reverse Current (rated dc voltage)	I_R				
$T_C = 25^oC$		–	25	50	μA
$T_C = 100^oC$		–	1.0	2.0	mA

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time	t_{rr}				ns
(I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16)		–	150	200	
(I_{FM} = 36 Amp, di/dt = 25 A/μs, Figure 17)		–	200	400	
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16)	$I_{RM(REC)}$	–	2.0	3.0	Amp



	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.86	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

MECHANICAL CHARACTERISTICS

Case: Welded, hermetically sealed
FINISH: All external surfaces corrosion resistant and readily solderable
POLARITY: Cathode to Case
WEIGHT: 17 Grams (Approcimately)
MOUNTING TORQUE: 25 in. lb max.

FIGURE 1 – FORWARD VOLTAGE

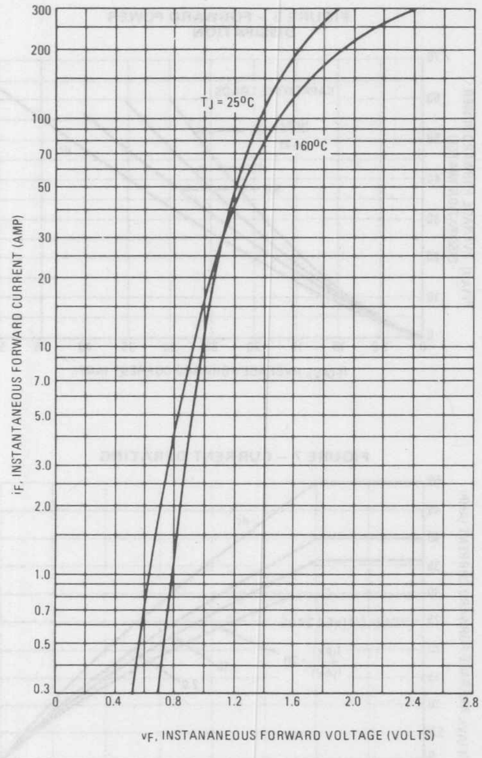
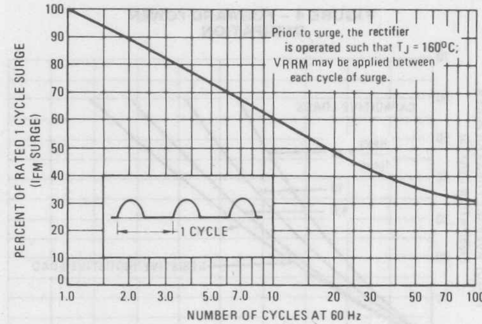
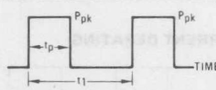


FIGURE 2 – MAXIMUM SURGE CAPABILITY



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

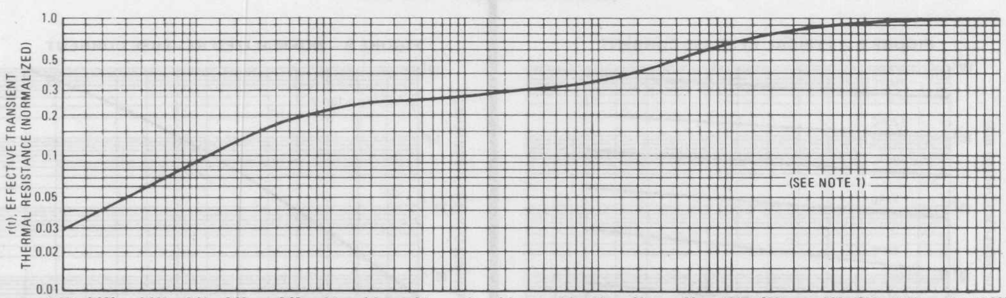
$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 3, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

FIGURE 3 – THERMAL RESPONSE



SINE WAVE INPUT

FIGURE 4 – FORWARD POWER DISSIPATION

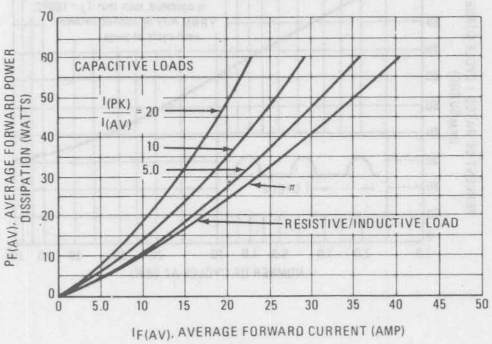


FIGURE 6 – CURRENT DERATING

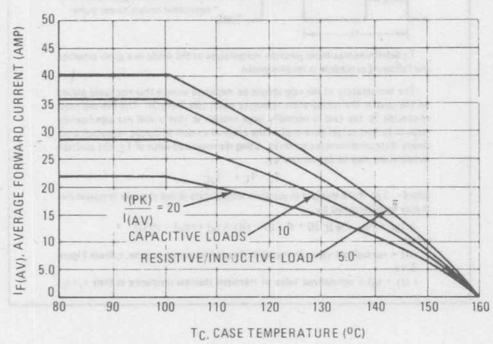
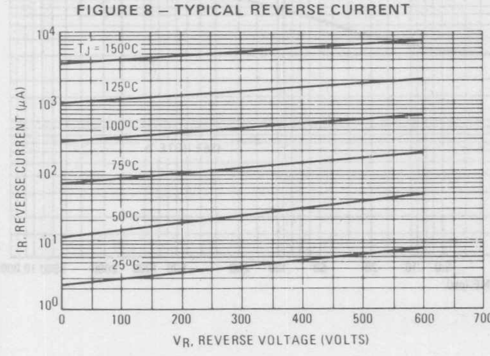


FIGURE 8 – TYPICAL REVERSE CURRENT



SQUARE WAVE INPUT

FIGURE 5 – FORWARD POWER DISSIPATION

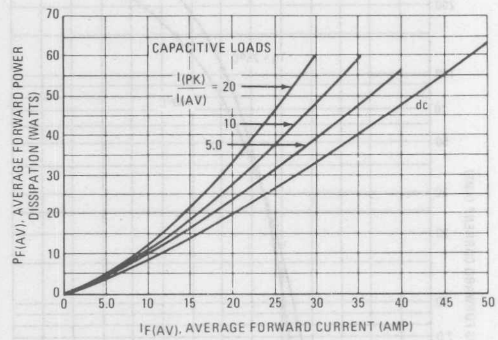


FIGURE 7 – CURRENT DERATING

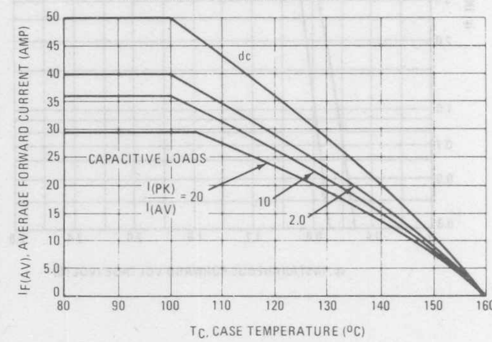


FIGURE 9 – NORMALIZED REVERSE CURRENT

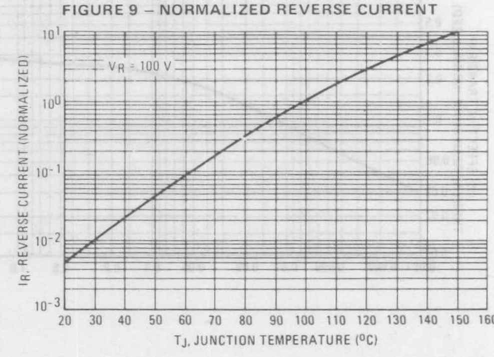


FIGURE 10 – FORWARD RECOVERY TIME

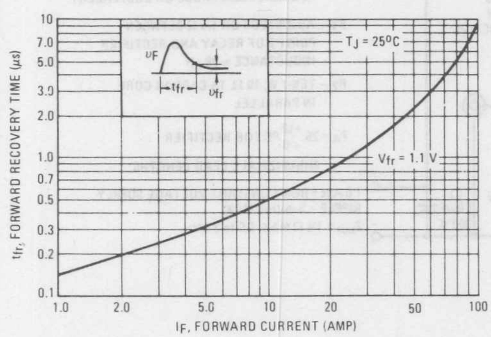
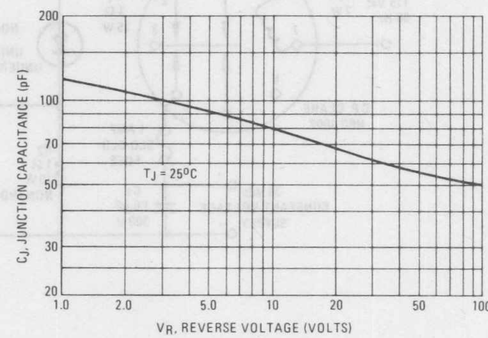


FIGURE 11 – JUNCTION CAPACITANCE



TYPICAL RECOVERED STORED CHARGE DATA

(See Note 2)

FIGURE 12 – $T_J = 25°C$

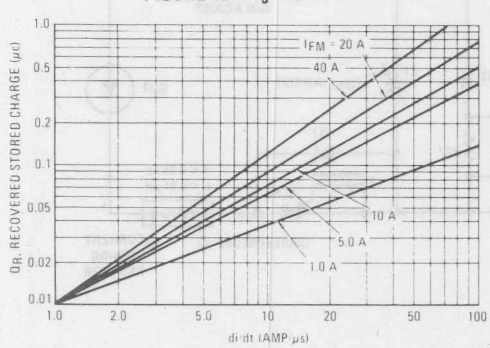


FIGURE 13 – $T_J = 75°C$

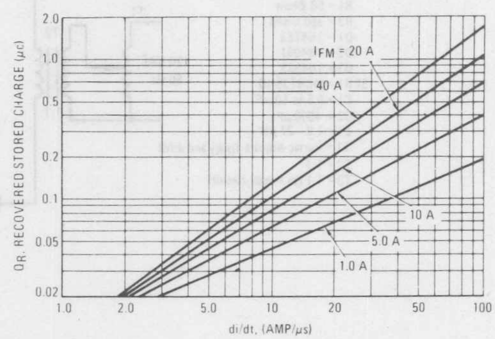


FIGURE 14 – $T_J = 100°C$

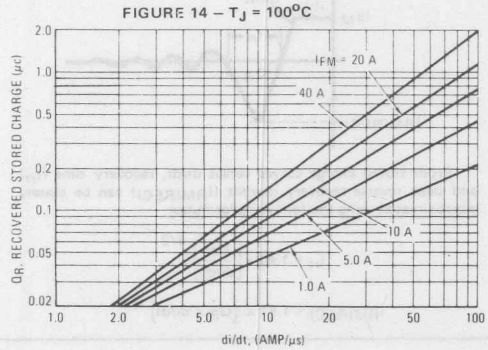


FIGURE 15 – $T_J = 150°C$

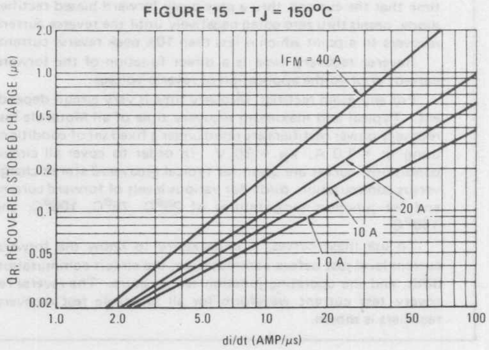
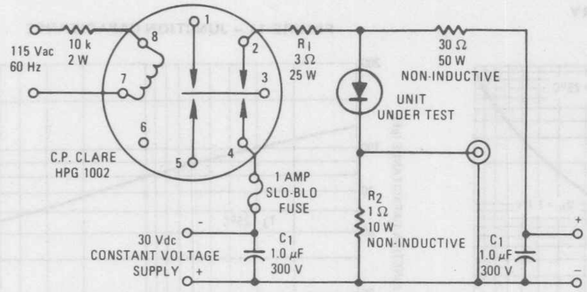


FIGURE 16 – REVERSE RECOVERY CIRCUIT



A – TEKTRONIX 545A, K PLUG IN PRE-AMP, P6000 PROBE OR EQUIVALENT

R_1 – ADJUSTED FOR 1.4 Ω BETWEEN POINT 2 OF RELAY AND RECTIFIER INDUCTANCE ≈ 38 μH

R_2 – TEN-1 W, 10 Ω, 1% CARBON CORE IN PARALLEL

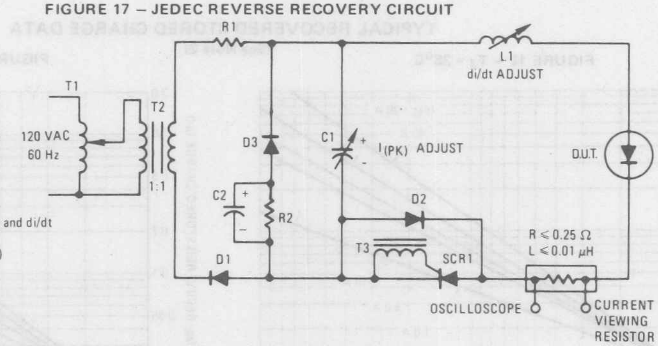
$T_A = 25\ ^{+10}_{-0}\ ^{\circ}C$ FOR RECTIFIER

MINIMIZE ALL LEAD LENGTHS

1.0 Adc FROM CONSTANT VOLTAGE SUPPLY
RIPPLE = 3 mVrms MAX
$Z_{out} = 1\frac{1}{2}\ \Omega$ MAX, DC to 2 kHz

FIGURE 17 – JEDEC REVERSE RECOVERY CIRCUIT

R1 = 50 Ohms
R2 = 250 Ohms
D1 = 1N4723
D2 = 1N4001
D3 = 1N4933
SCR1 = MCR729-10
C1 = 0.5 to 50 μF
C2 ≈ 4000 μF
L1 = 1.0 - 27 μH
T1 = Variac Adjusts $I_{(PK)}$ and di/dt
T2 = 1:1
T3 = 1:1 (to trigger circuit)



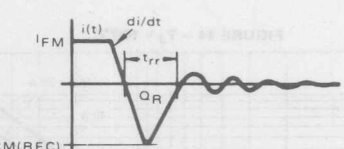
NOTE 2

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

MOTOROLA

MR870 MR871 MR872 MR874 MR876

Designers Data Sheet

STUD MOUNTED FAST RECOVERY POWER RECTIFIERS

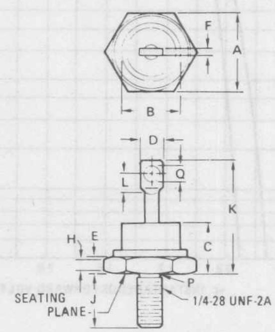
. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference, sonar power supplies and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 150 nanoseconds providing high efficiency at frequencies to 250 kHz.

Designer's Data for "Worst Case" Conditions

The Designers Data sheets permit the design of most circuits entirely from the information presented. Limit curves – representing boundaries on device characteristics – are given to facilitate "worst case" design.

FAST RECOVERY POWER RECTIFIERS

50-600 VOLTS
50 AMPERES



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	16.94	17.45	0.667	0.687
B	–	16.94	–	0.667
C	–	11.43	–	0.450
D	–	9.53	–	0.375
E	2.92	5.08	0.115	0.200
F	–	2.03	–	0.080
H	1.52	–	0.060	–
J	10.72	11.51	0.422	0.453
K	–	25.40	–	1.000
L	3.86	–	0.152	–
P	5.59	6.32	0.220	0.249
Q	3.56	4.45	0.140	0.175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

CASE 257-01
DO-5

MAXIMUM RATINGS

Rating	Symbol	MR870	MR871	MR872	MR874	MR876	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	450	650	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	280	420	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_C = 100^oC$)	I_O	← 50 →					Amps
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}	← 400 →					Amps
Operating Junction Temperature Range	T_J	← -65 to +160 →					^oC
Storage Temperature Range	T_{stg}	← -65 to +175 →					^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	0.8	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage (i_F = 157 Amp, $T_J = 160^oC$)	v_F	–	1.3	1.6	Volts
Forward Voltage (I_F = 50 Amp, $T_C = 25^oC$)	V_F	–	1.1	1.4	Volts
Reverse Current (rated dc voltage) $T_C = 25^oC$ $T_C = 100^oC$	I_R	– –	25 1.0	50 2.0	μA mA

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16) (I_{FM} = 36 Amp, di/dt = 25 A/μs, Figure 17)	t_{rr}	 – –	 150 240	 200 400	ns
Reverse Recovery Current (I_F = 1.0 Amp to V_R = 30 Vdc, Figure 16)	$I_{RM(REC)}$	–	2.0	3.0	Amp

MECHANICAL CHARACTERISTICS

Case: Welded, hermetically sealed
FINISH: All external surfaces corrosion resistant and readily solderable
POLARITY: Cathode to Case
WEIGHT: 17 Grams (Approcimately)
MOUNTING TORQUE: 25 in. lb max.

FIGURE 1 – FORWARD VOLTAGE

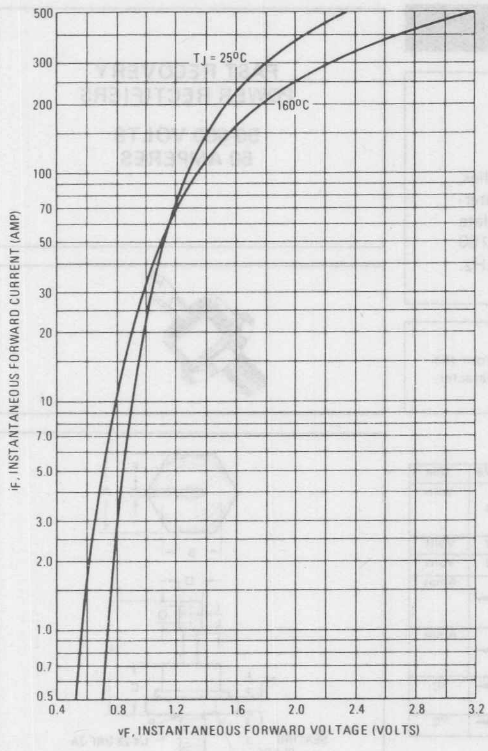
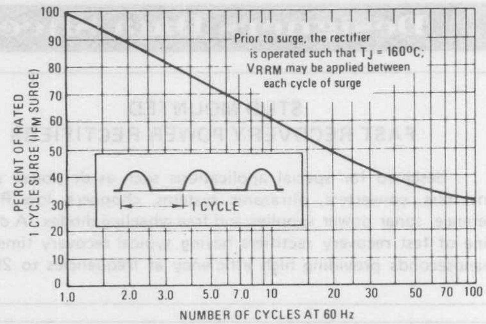
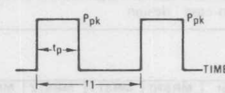


FIGURE 2 – MAXIMUM SURGE CAPABILITY



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see Note 3). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

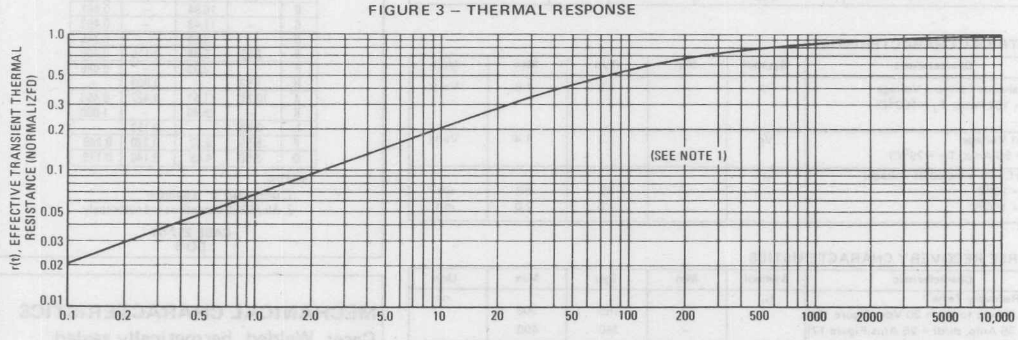
$$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC} \left[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)\right]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 3, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

FIGURE 3 – THERMAL RESPONSE



SINE WAVE INPUT

FIGURE 4 – FORWARD POWER DISSIPATION

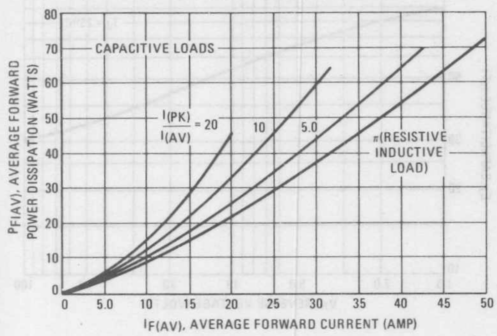


FIGURE 6 – CURRENT DERATING

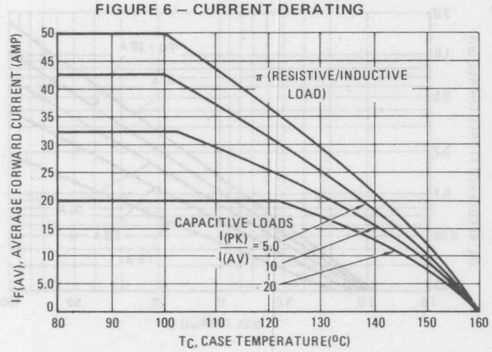
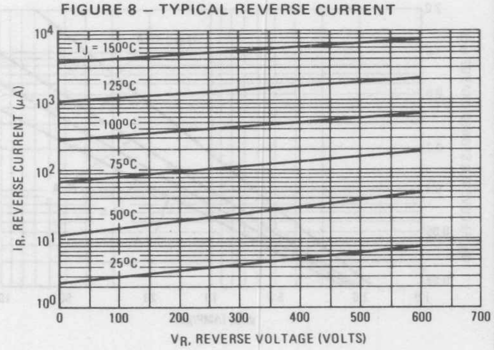


FIGURE 8 – TYPICAL REVERSE CURRENT



SQUARE WAVE INPUT

FIGURE 5 – FORWARD POWER DISSIPATION

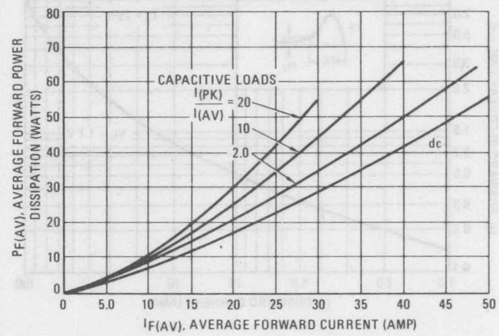


FIGURE 7 – CURRENT DERATING

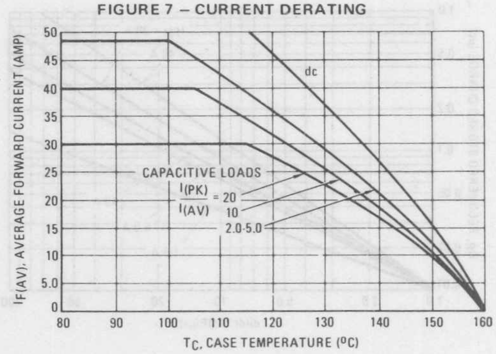
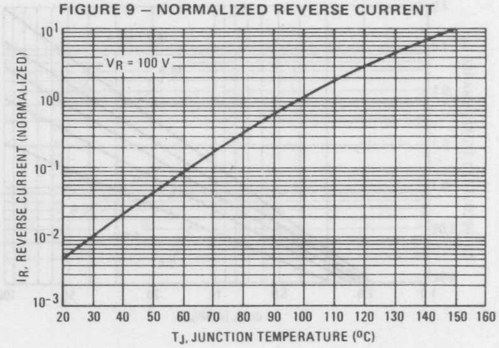


FIGURE 9 – NORMALIZED REVERSE CURRENT



TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 10 – FORWARD RECOVERY TIME

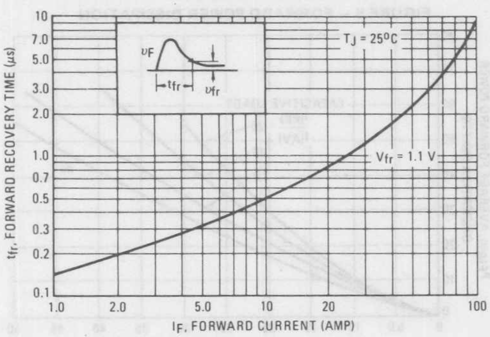
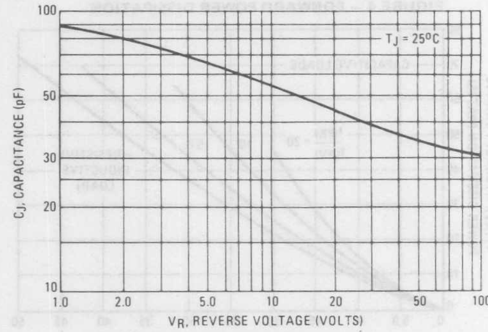


FIGURE 11 – JUNCTION CAPACITANCE



TYPICAL RECOVERED STORED CHARGE DATA

(See Note 2)

FIGURE 12 – $T_J = 25^oC$

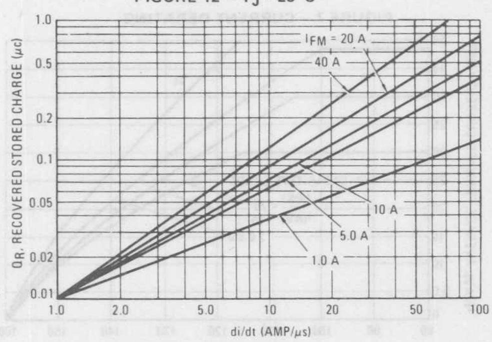


FIGURE 13 – $T_J = 75^oC$

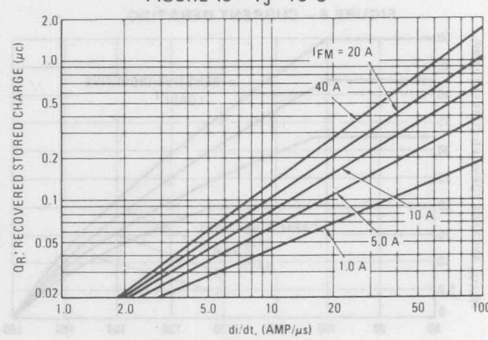


FIGURE 14 – $T_J = 100^oC$

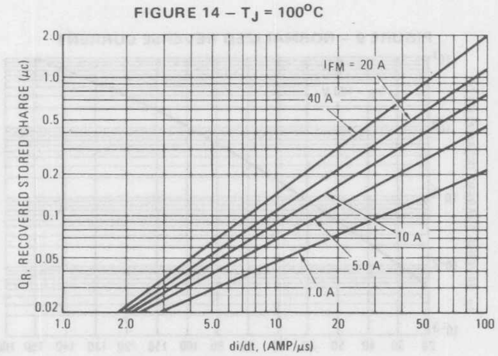


FIGURE 15 – $T_J = 150^oC$

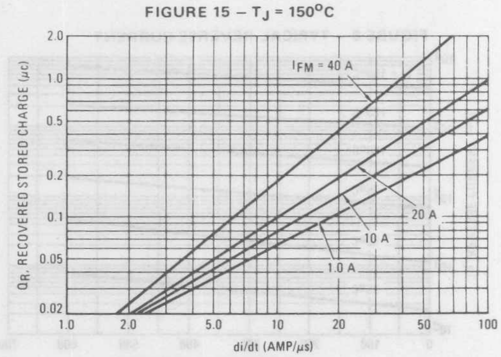
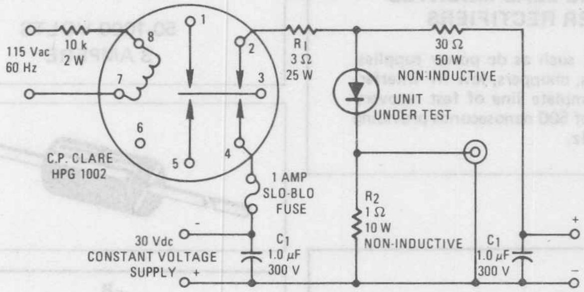


FIGURE 16 – REVERSE RECOVERY CIRCUIT



A – TEKTRONIX 545A, K PLUG IN PRE-AMP, P6000 PROBE OR EQUIVALENT

R_1 – ADJUSTED FOR 1.4 Ω BETWEEN POINT 2 OF RELAY AND RECTIFIER INDUCTANCE ≈ 38 μH

R_2 – TEN-1 W, 10 Ω, 1% CARBON CORE IN PARALLEL

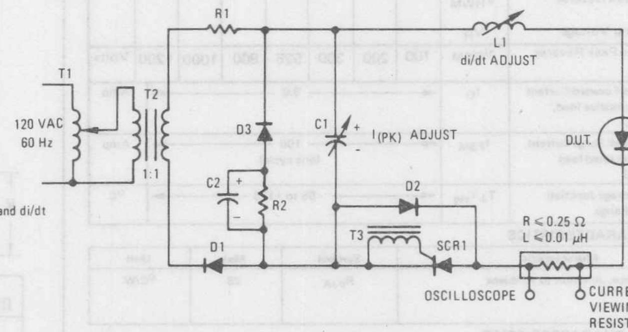
$T_A = 25\ ^{+10}_{-0}\ ^\circ C$ FOR RECTIFIER

MINIMIZE ALL LEAD LENGTHS

1.0 Adc FROM CONSTANT VOLTAGE SUPPLY
RIPPLE = 3 mVrms MAX
Z_{out} = 1½ Ω MAX, DC to 2 kHz

FIGURE 17 – JEDEC REVERSE RECOVERY CIRCUIT

R1 = 50 Ohms
R2 = 250 Ohms
D1 = 1N4723
D2 = 1N4001
D3 = 1N4933
SCR1 = MCR729-10
C1 = 0.5 to 50 μF
C2 ≈ 4000 μF
L1 = 1.0 - 27 μH
T1 = Variac Adjusts $I_{(PK)}$ and di/dt
T2 = 1:1
T3 = 1:1 (to trigger circuit)



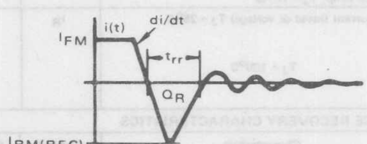
NOTE 2

Reverse recovery time is the period which elapses from the time that the current, thru a previously forward biased rectifier diode, passes thru zero going negatively until the reverse current recovers to a point which is less than 10% peak reverse current.

Reverse recovery time is a direct function of the forward current prior to the application of reverse voltage.

For any given rectifier, recovery time is very circuit dependent. Typical and maximum recovery time of all Motorola fast recovery power rectifiers are rated under a fixed set of conditions using I_F = 1.0 A, V_R = 30 V. In order to cover all circuit conditions, curves are given for typical recovered stored charge versus commutation di/dt for various levels of forward current and for junction temperatures of 25°C, 75°C, 100°C, and 150°C.

To use these curves, it is necessary to know the forward current level just before commutation, the circuit commutation di/dt, and the operating junction temperature. The reverse recovery test current waveform for all Motorola fast recovery rectifiers is shown.



From stored charge curves versus di/dt, recovery time (t_{rr}) and peak reverse recovery current ($I_{RM(REC)}$) can be closely approximated using the following formulas:

$$t_{rr} = 1.41 \times \left[\frac{Q_R}{di/dt}\right]^{1/2}$$

$$I_{RM(REC)} = 1.41 \times \left[Q_R \times di/dt\right]^{1/2}$$

MOTOROLA

MR 910 SERIES

Designers Data Sheet

SUBMINIATURE SIZE, AXIAL LEAD MOUNTED FAST RECOVERY POWER RECTIFIERS

. . . designed for special applications such as dc power supplies, inverters, converters, ultrasonic systems, choppers, low RF interference and free wheeling diodes. A complete line of fast recovery rectifiers having typical recovery time of 500 nanoseconds providing high efficiency at frequencies to 100 kHz.

FAST RECOVERY POWER RECTIFIERS

50-1000 VOLTS
3 AMPERE

MAXIMUM RATINGS

Rating	Symbol	MR 910	MR 911	MR 912	MR 914	MR 916	MR 917	MR 918	Units
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	100	200	300	525	800	1000	1200	Volts
Average Rectified Forward Current (Single phase resistive load, $T_A = 90^oC$)	I_O				3.0				Amp
Non-Repetitive Peak Surge Current (surge applied at rated load conditions)	I_{FSM}				100 (one cycle)				Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}				-65 to +175				^oC

THERMAL CHARACTERISTICS

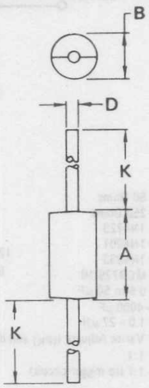
Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	28	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage ($I_F = 9.4$ Amp, $T_J = 175^oC$)	v_F	–	0.9	1.1	Volts
Forward Voltage ($I_F = 3.0$ Amp, $T_J = 25^oC$)	V_F	–	1.04	1.25	Volts
Reverse Current (rated dc voltage) $T_J = 25^oC$	I_R	–		10	μA
$T_J = 100^oC$		–	–	300	μA

REVERSE RECOVERY CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Reverse Recovery Time ($I_F = 1.0$ Amp to $V_R = 30$ Vdc)	t_{rr}			750	ns
Reverse Recovery Current ($I_F = 1.0$ Amp to $V_R = 30$ Vdc)	$I_{RM(REC)}$	–	–	3.0	Amp



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	9.40	9.65	0.370	0.380
B	4.83	5.33	0.190	0.210
D	1.22	1.32	0.048	0.052
K	26.97	27.23	1.062	1.072

CASE 267-01

MECHANICAL CHARACTERISTICS

Case: Void Free, Transfer Molded
Finish: External Leads are Plated, Leads are readily Solderable
Polarity: Indicated by Cathode Band

Weight: 1.1 Grams (Approximately)
Maximum Lead Temperature for Soldering Purposes:
240^{o}C, 1/8" from case for 10 s at 5,0 lb. tension

STATIC CHARACTERISTICS

FIGURE 1 – FORWARD VOLTAGE

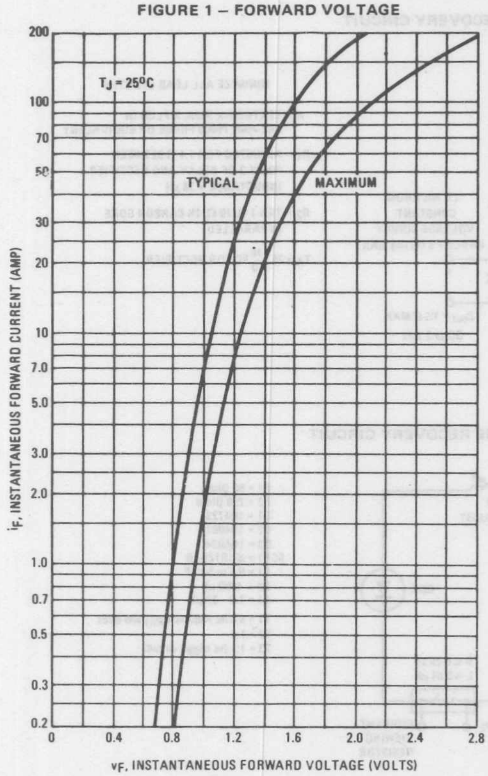


FIGURE 2 – MAXIMUM SURGE CAPABILITY

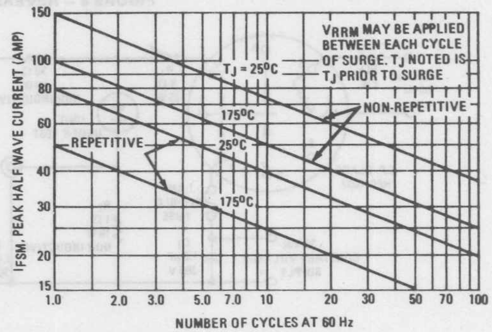
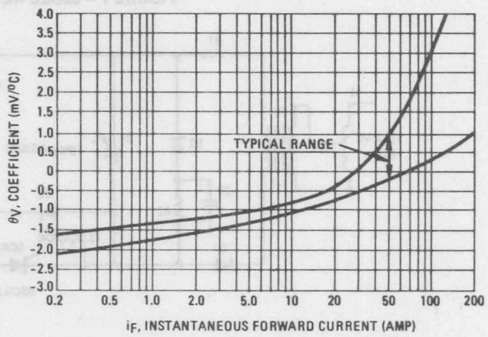
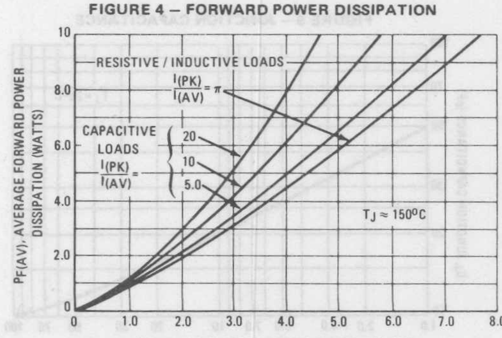


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT



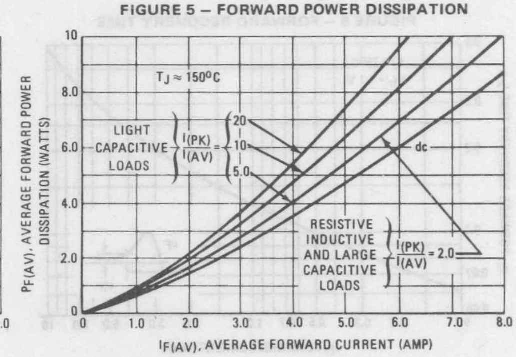
SINE WAVE INPUT

FIGURE 4 – FORWARD POWER DISSIPATION



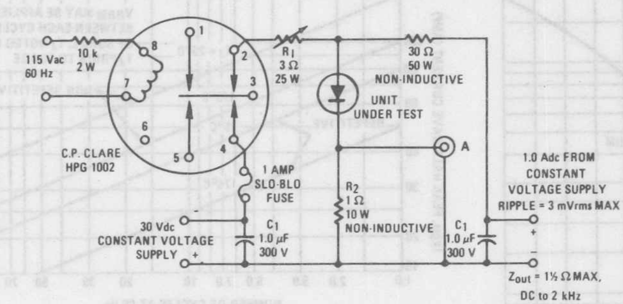
SQUARE WAVE INPUT

FIGURE 5 – FORWARD POWER DISSIPATION



DYNAMIC CHARACTERISTICS

FIGURE 6 – REVERSE RECOVERY CIRCUIT



MINIMIZE ALL LEAD LENGTHS

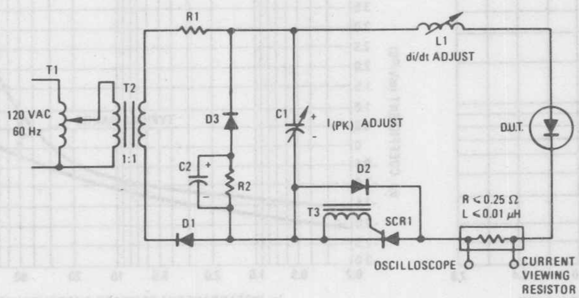
A – TEKTRONIX 545A, K PLUG IN PRE-AMP, P6000 PROBE OR EQUIVALENT

R_1 – ADJUSTED FOR 1.4 Ω BETWEEN POINT 2 OF RELAY AND RECTIFIER INDUCTANCE ≈ 38 μH

R_2 – TEN-1 W, 10 Ω, 1% CARBON CORE IN PARALLEL

$T_A = 25\,^{+10}_{-0}$ °C FOR RECTIFIER

FIGURE 7 – JEDEC REVERSE RECOVERY CIRCUIT



R1 = 50 Ohms
R2 = 250 Ohms
D1 = 1N4723
D2 = 1N4001
D3 = 1N4934
SCR1 = MCR729-10
C1 = 0.5 to 50 μF
C2 ≈ 4000 μF
L1 = 1.0 - 27 μH
T1 = Variac Adjusts $I_{(PK)}$ and di/dt
T2 = 1:1
T3 = 1:1 (to trigger circuit)

FIGURE 8 – FORWARD RECOVERY TIME

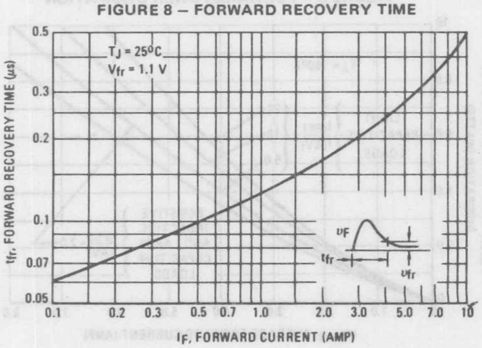


FIGURE 9 – JUNCTION CAPACITANCE

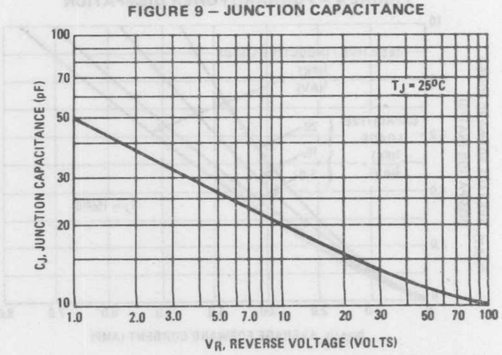


FIGURE 10 – THERMAL RESPONSE

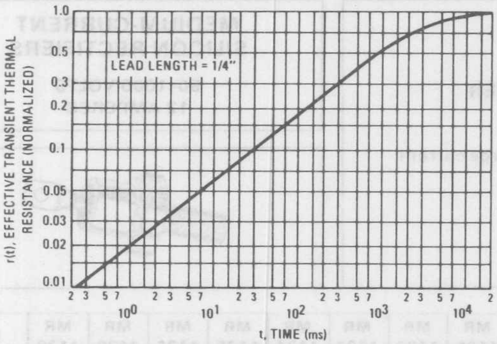
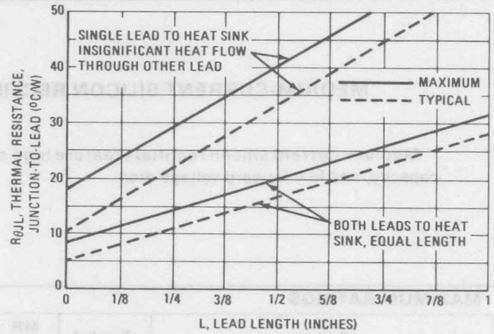


FIGURE 11 – STEADY STATE THERMAL RESISTANCE



NOTE 1

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the lead should be measured using a thermocouple placed on the lead as close as possible to the tie point. The thermal mass connected to the tie point is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_L, the junction temperature may be determined by:

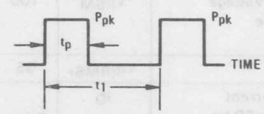
$$T_J = T_L + \Delta T_{JL}$$

where ΔT_{JL} is the increase in junction temperature above the lead temperature. It may be determined by:

$$\Delta T_{JL} = P_{pk} \cdot R_{\theta JL} \, [D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where $r(t)$ = normalized value of transient thermal resistance at time t from Figure 29, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.



DUTY CYCLE = t_p/t_1
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

NOTE 2

Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. For a given total lead length, lowest values occur when one side of the rectifier is brought as close as possible to the heat sink. Terms in the model signify:

T_A = Ambient Temperature	$R_{\theta S}$ = Thermal Resistance, Heat Sink to Ambient
T_L = Lead Temperature	$R_{\theta L}$ = Thermal Resistance, Lead to Heat Sink
T_C = Case Temperature	$R_{\theta J}$ = Thermal Resistance, Junction to Case
T_J = Junction Temperature	P_D = Total Power Dissipation = $P_F + P_R$
	P_F = Forward Power Dissipation
	P_R = Reverse Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.)
Values for thermal resistance components are:

$R_{\theta L}$ = 46°C/W/IN. Typically and 48°C/W/IN Maximum.
$R_{\theta J}$ = 10°C/W Typically and 16°C/W Maximum.

The maximum lead temperature may be found as follows:

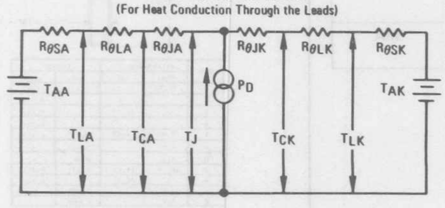
$$T_L = T_{J(max)} - \Delta T_{JL}$$

where

ΔT_{JL} can be approximated as follows:

$\Delta T_{JL} \approx R_{\theta JL} \cdot P_D$; P_D is the sum of forward and reverse power dissipation shown in Figures 2 and 4 for sine wave operation and Figures 3 and 5 for square wave operation.

THERMAL CIRCUIT MODEL
(For Heat Conduction Through the Leads)



NOTE 3

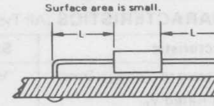
Data shown for thermal resistance junction-to-ambient ($R_{\theta JA}$) for the mountings shown is to be used as typical guideline values for preliminary engineering or in case the tie point temperature cannot be measured.

TYPICAL VALUES FOR $R_{\theta JA}$ IN STILL AIR

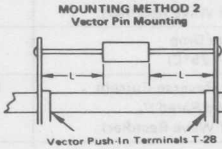
MOUNTING METHOD	LEAD LENGTH, L (IN)				$R_{\theta JA}$
	1/8	1/4	1/2	3/4	
1	50	51	53	55	°C/W
2	58	59	61	63	°C/W
3	28				°C/W

MOUNTING METHOD 1

P.C. Board Where Available Copper Surface area is small.

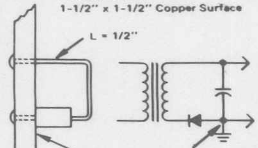


MOUNTING METHOD 2
Vector Pin Mounting



MOUNTING METHOD 3

P.C. Board with 1-1/2" x 1-1/2" Copper Surface



MOTOROLA

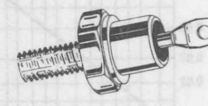
MR 1120, M SERIES

MEDIUM-CURRENT SILICON RECTIFIER

Medium-current silicon rectifiers feature high surge current capacity, and low forward voltage drop.

MEDIUM-CURRENT SILICON RECTIFIERS

50-1000 VOLTS
12 AMPERES

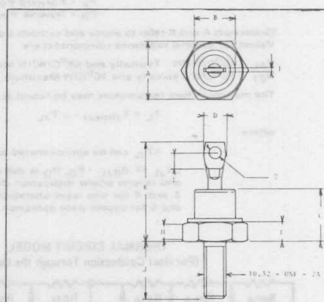


MAXIMUM RATINGS

Rating	Symbol	MR 1120	MR 1121	MR 1122	MR 1123	MR 1124	MR 1125	MR 1126	MR 1128	MR 1130	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	500	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage (one half-wave, single phase, 60 cycle peak)	V_{RSM}	100	200	300	400	500	600	720	100	1200	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	350	420	560	700	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz, $T_C = 150°C$)	I_O	← 12 →									Amp
Peak Repetitive Forward Current ($T_C = 150°C$)	I_{FRM}	← 75 →									Amp
Non-Repetitive Peak Surge Current (superimposed on rated current at rated voltage, $T_C = 150°C$)	I_{FSM}	← 300 (for 1/2 cycle) →									Amp
I^2t Rating (non-repetitive, 1 ms $<t<$ 8.3 ms)	I^2t	← 375 →									$A_{(rms)}^2s$
Maximum Junction Operating and Storage Temperature Range	T_J, T_{stg}	← -65 to +190 →									°C

ELECTRICAL CHARACTERISTICS (All Types)

Characteristic	Symbol	Max	Unit
Full Cycle Average Forward Voltage Drop (I_O = 12 Amps and Rated V_r, $T_C = 150°C$, Half Wave Rectifier)	$V_{F(AV)}$	0.55	Volts
DC Forward Voltage Drop (I_F = 12 Adc, $T_C = 25°C$)	V_F	1.0	Volts
Full Cycle Average Reverse Current (I_O = 12 Amps and Rated V_r, $T_C = 150°C$, Half Wave Rectifier)	$I_{R(AV)}$	1.5	mA
DC Reverse Current (Rated V_R, $T_C = 25°C$)	I_R	0.5	mA



DIM	MILLIMETERS min.	MILLIMETERS max.	INCHES min.	INCHES max.
A	10.77	11.10	0.424	0.437
B		-		0.424
C	-	10.29		0.450
D			-	0.250
E	1.91	4.45	0.075	0.175
F	0.6	-	0.023	-
H	1.5	-	0.06	-
J	10.72	11.51	0.422	0.453
K	-	20.32	-	0.800
L	2.0	-	0.078	-
Q	1.5	-	0.060	

CASE 56
DO-4

MR 1120, M SERIES

THERMAL CHARACTERISTICS

Maximum Steady State DC Thermal Resistance, $R_{\theta JC}$: 2.5°C/Watt

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed construction.

FINISH: All external surfaces corrosion-resistant and the terminal lug is readily solderable.

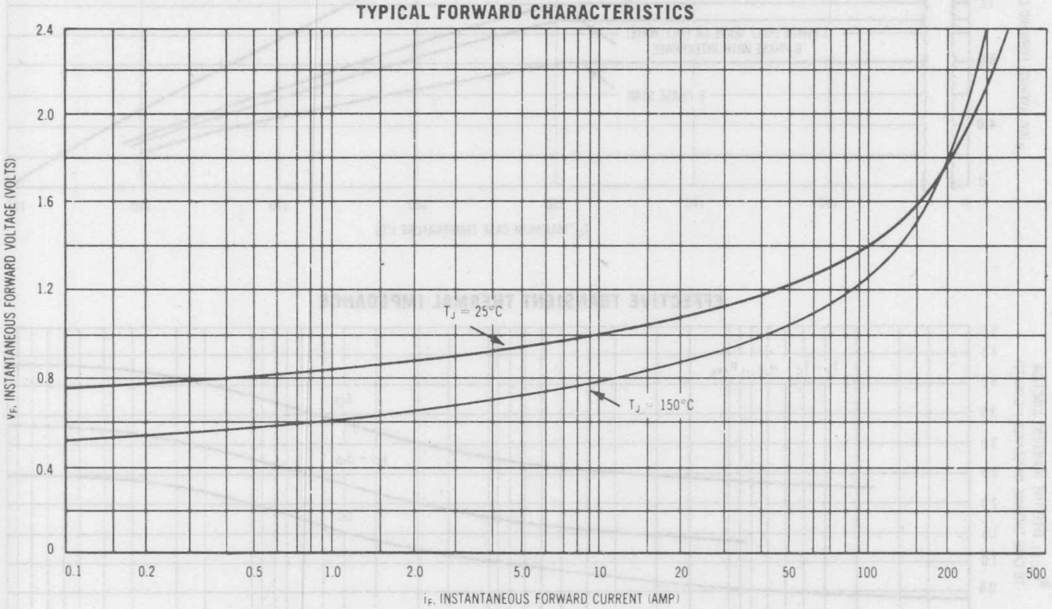
POLARITY: CATHODE-TO-CASE (reverse polarity units are available upon request and are designated by an „R" suffix i. e. MR112OR).

MOUNTING POSITIONS: Any

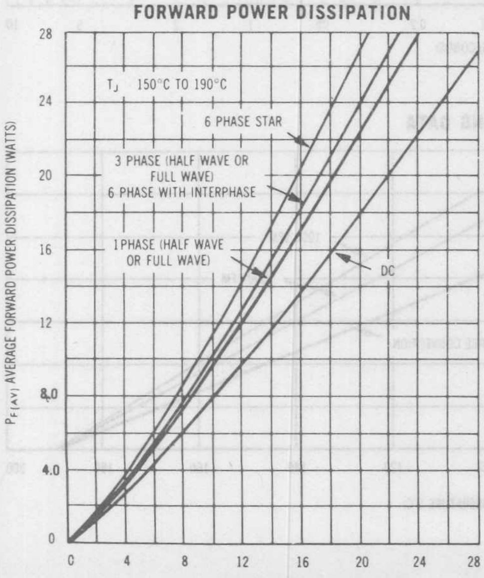
STUD TORQUE: 15 in-lbs maximum.

METRIC THREAD upon request i. e. MR1120M

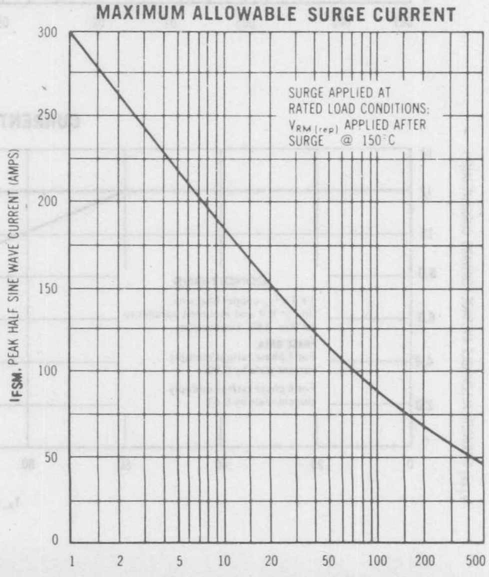
TYPICAL FORWARD CHARACTERISTICS



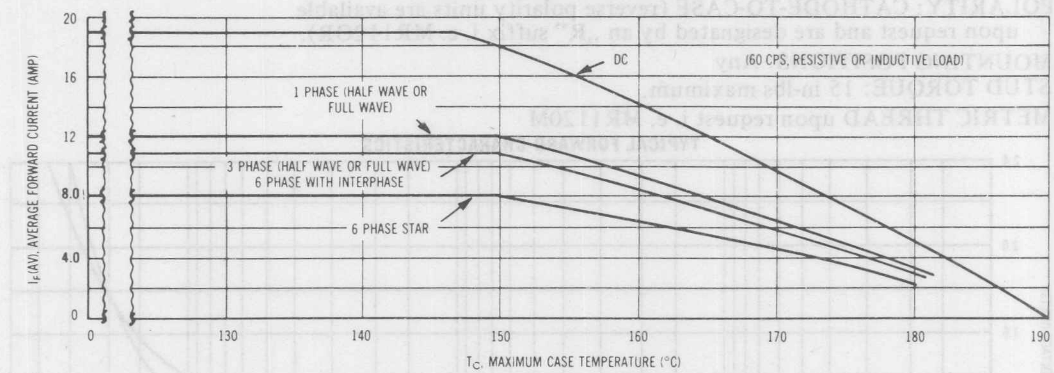
FORWARD POWER DISSIPATION



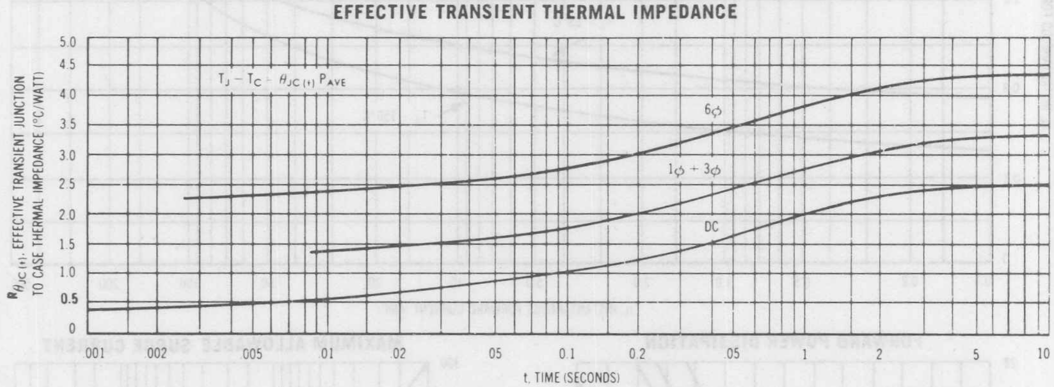
MAXIMUM ALLOWABLE SURGE CURRENT



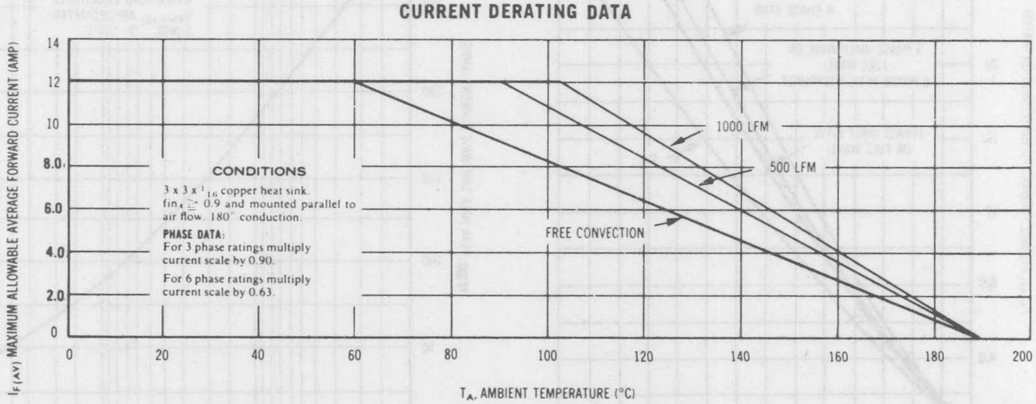
MAXIMUM CURRENT RATINGS



EFFECTIVE TRANSIENT THERMAL IMPEDANCE



CURRENT DERATING DATA



MR1215SL
MR1219SL
MR1815SL
MR1819SL

MOTOROLA

Designers Data Sheet

MULTI-CELL POWER RECTIFIERS

. . . designed for applications requiring low power dissipation and high inrush surge current.

A heavy copper base/heat sink provides low thermal resistance and lowest operating junction temperatures.

Designers Data for "Worst Case" Conditions

The Designers Data Sheets permit the design of most circuits entirely from the information presented. Limit curves — representing boundaries on device characteristics — are given to facilitate "worst case" design.

HIGH-CURRENT SILICON RECTIFIERS

80/100 AMPERE
300, 600 VOLTS
DIFFUSED JUNCTIONS

MAXIMUM RATINGS

Rating	Symbol	MR1215SL MR1815SL	MR1219SL MR1819SL	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	300	600	Volts
Nonrepetitive Peak Reverse Voltage (one half-wave, single phase, 60 Hz peak)	V_{RSM}	400	720	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	210	420	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz, see Figure 3) $T_C = 135°C$ $T_C = 150°C$	I_O	← 100 → ← 80 →		Amp
Nonrepetitive Peak Surge Currents (super applied at rated load conditions, see Figure 5) $T_C = 150°C$	I_{FSM}	← 2,000 (for 1/2 cycle) → ← 1,200 (for six consecutive cycles) →		Amp
I^2t Rating (nonrepetitive, for t greater than 1 ms and less than 8.3 ms)	I^2t	← 8,300 →		A^2s
Operating and Storage Junction Temperature Range (see Figure 4 for other conditions)	T_J, T_{stg}	← -65 to +190 →		°C

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Max	Unit
Full Cycle Average Forward Voltage Drop (rated I_O and V_r, single phase 60 Hz, T_C = 150°C)	$V_{F(AV)}$	0.4	Volts
Full Cycle Average Reverse Current (rated I_O and V_r, single phase 60 Hz, T_C = 150°C)	$I_{R(AV)}$	15	mA

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	0.40	°C/Watt

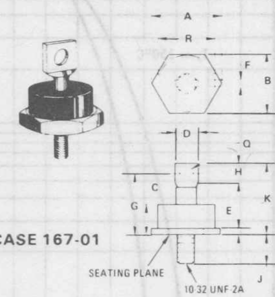
MECHANICAL CHARACTERISTIC

CASE: Molded, hermetically sealed construction

POLARITY: Cathode to Case (reverse polarity devices are Anode to Case and are designated by an "R" suffix i.e. MR1215SLR).

MOUNTING POSITION: Any.

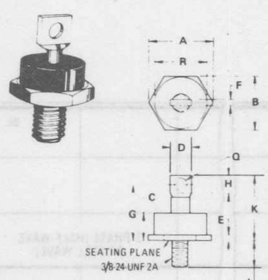
STUD MOUNTING TORQUES: 25 in-lb min., 30 in-lb max.



CASE 167-01

MR1215SL and MR1219SL

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	-	36.83	-	1.450
B	31.37	32.13	1.235	1.265
C	13.72	17.91	0.540	0.705
D	10.80	13.34	0.425	0.525
E	2.92	3.43	0.115	0.135
F	2.67	3.43	0.105	0.135
G	29.21	34.29	1.150	1.350
H	12.70	-	0.500	-
J	10.77	12.70	0.424	0.500
K	34.93	44.45	1.375	1.750
Q	6.10	6.60	0.240	0.260
R	-	30.48		1.200



CASE 189-01

MR1815SL and MR1819SL

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	33.02	36.83	1.300	1.450
B	31.37	32.13	1.235	1.265
C	13.72	17.91	0.540	0.705
D	12.70	13.34	0.500	0.525
E	2.92	3.43	0.115	0.135
F	2.67	3.43	0.105	0.135
G	29.21	34.29	1.150	1.350
H	12.70	16.76	0.500	0.660
J	15.06	16.69	0.593	0.657
K	34.93	44.45	1.375	1.750
Q	6.10	6.60	0.240	0.260
R	–	30.48	–	1.200

NOTES:
1. TERM. 1 CRIMPED LUG.
2. ANGULAR ORIENTATION OF LUG UNDEFINED
3. DIM "H" LUG FLAT ZONE.

FIGURE 1 – MAXIMUM FORWARD VOLTAGE DROP

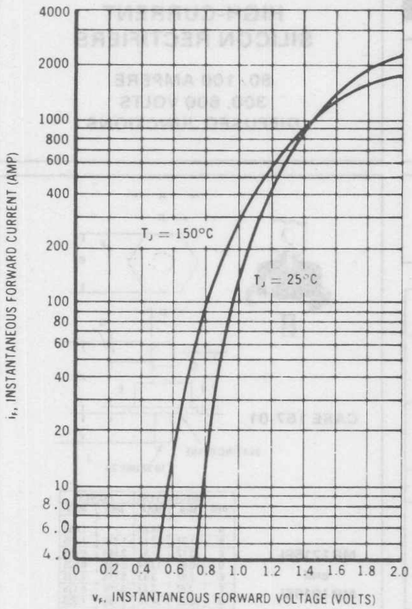


FIGURE 2 – MAXIMUM FORWARD POWER DISSIPATION

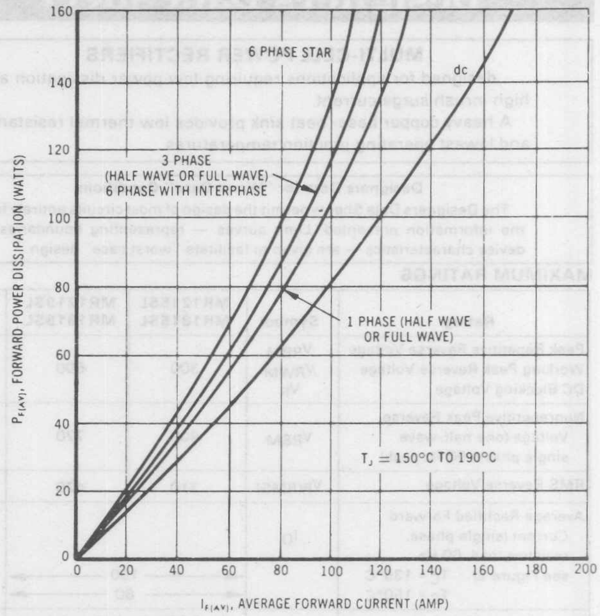


FIGURE 3 – MAXIMUM CURRENT RATINGS

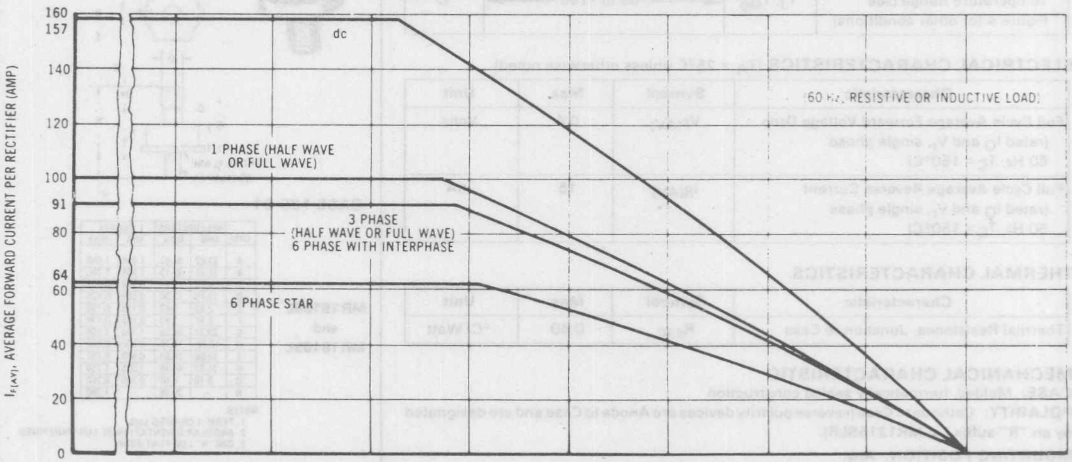


FIGURE 4 – EFFECTIVE TRANSIENT THERMAL IMPEDANCE

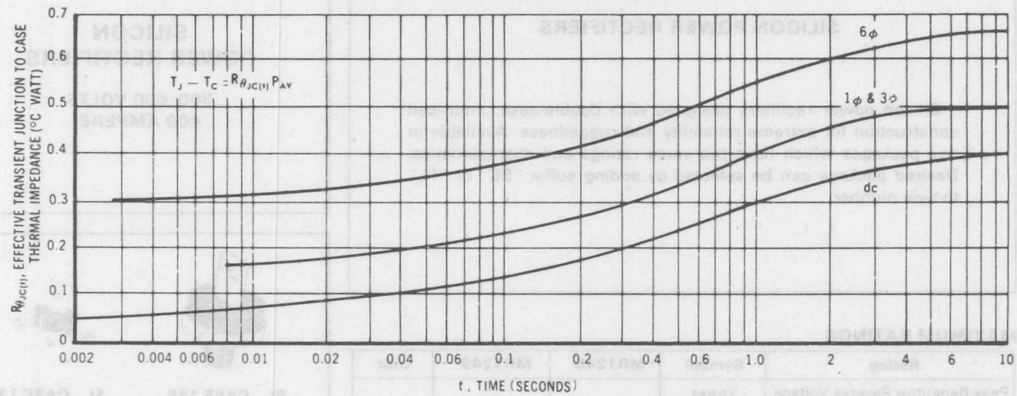


FIGURE 5 – MAXIMUM ALLOWABLE SURGE CURRENT

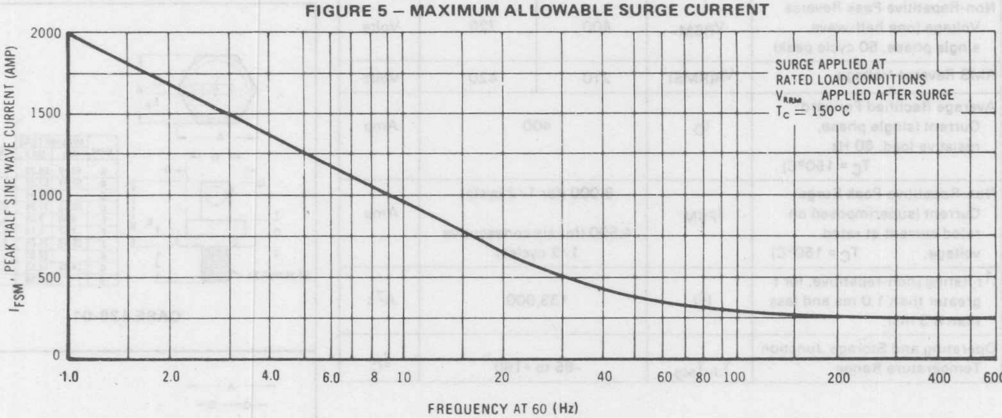
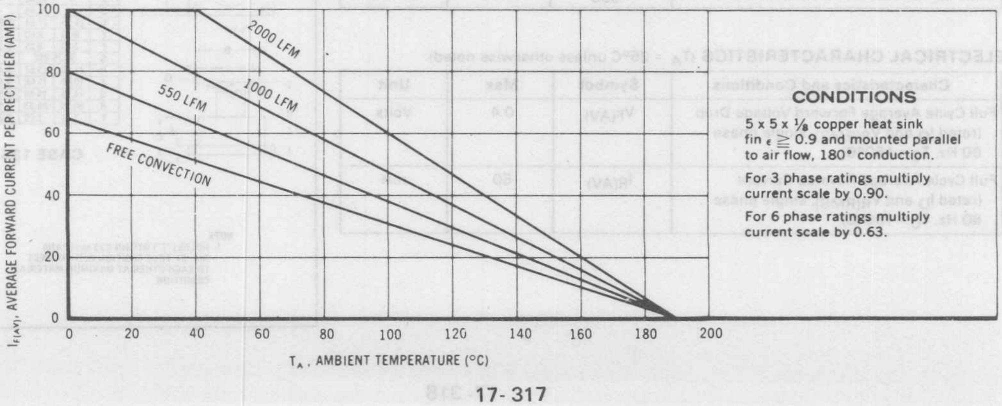


FIGURE 6 – MAXIMUM CURRENT DERATING DATA



MOTOROLA

SILICON POWER RECTIFIERS

Silicon power rectifiers designed with double-case, multi-cell construction for extreme reliability and ruggedness. Available in two packages which have the same ratings and characteristics. Desired package can be selected by adding suffix "SL" or "FL" to type number.

SILICON POWER RECTIFIERS

300-600 VOLTS
400 AMPERE

SL CASE 128

FL CASE 135

MAXIMUM RATINGS

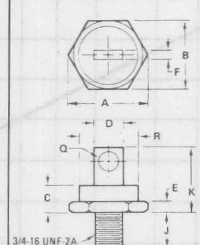
Rating	Symbol	MR1245	MR1249	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	300	600	Volts
Non-Repetitive Peak Reverse Voltage (one half-wave, single phase, 60 cycle peak)	V_{RSM}	400	720	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	210	420	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz, $T_C = 150°C$)	I_O	400		Amp
Non-Repetitive Peak Surge Current (superimposed on rated current at rated voltage, $T_C = 150°C$)	I_{FSM}	8,000 (for 1/2 cycle) 4,500 (for six consecutive 1/2 cycles)		Amp
I^2t Rating (non-repetitive, for t greater than 1.0 ms and less than 8.3 ms)	I^2t	133,000		A^2s
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +190		°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	0.075	°C/Watt

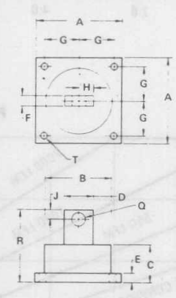
ELECTRICAL CHARACTERISTICS ($T_A = 25°C$ unless otherwise noted)

Characteristics and Conditions	Symbol	Max	Unit
Full Cycle Average Forward Voltage Drop (rated I_O and $V_{R(RMS)}$, single phase 60 Hz, $T_C = 150°C$)	$V_{F(AV)}$	0.4	Volts
Full Cycle Average Reverse Current (rated I_O and $V_{R(RMS)}$, single phase 60 Hz, $T_C = 150°C$)	$I_{R(AV)}$	50	mA



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	65.79	66.29	2.590	2.610
B	57.02	57.28	2.245	2.255
C	–	27.94	–	1.100
D	25.15	27.94	0.990	1.100
E	9.40	9.65	0.370	0.380
F	7.67	8.18	0.302	0.322
J	25.15	25.65	0.990	1.010
K	–	68.83	–	2.710
Q	14.02	14.53	0.552	0.572
R	–	55.88	–	2.200

CASE 128-01

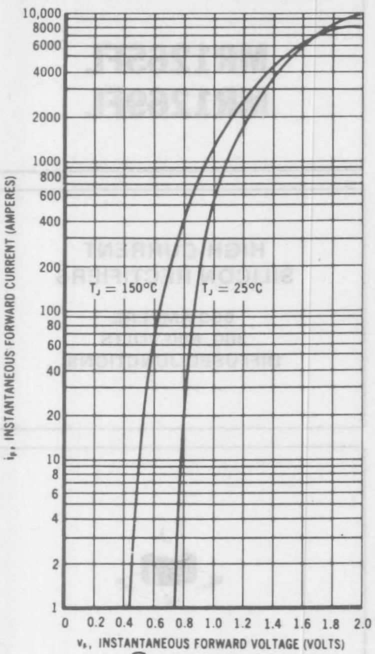


DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	75.95	76.45	2.990	3.010
B	–	55.88	–	2.200
C	–	25.40	–	1.000
D	25.15	27.94	0.990	1.100
E	6.10	6.60	0.240	0.260
F	7.80	8.05	0.307	0.317
G	31.75 BSC		1.250 BSC	
H	11.30	13.97	0.445	0.550
J	10.67	11.68	0.420	0.460
Q	14.15	14.40	0.557	0.567
R	50.80	60.33	2.000	2.375
T	7.01	7.26	0.276	0.286

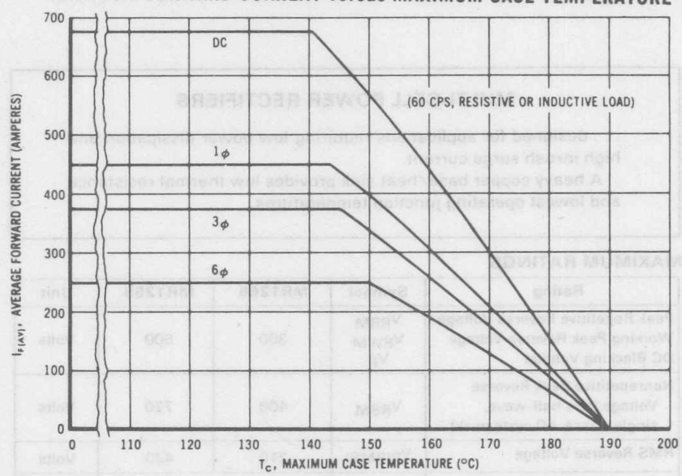
CASE 135-01

NOTE:
1. HOLES ("T") WITHIN 0.25 mm (0.010) DIA. OF TRUE POSITION WITH RESPECT TO EACH OTHER AT MAXIMUM MATERIAL CONDITION.

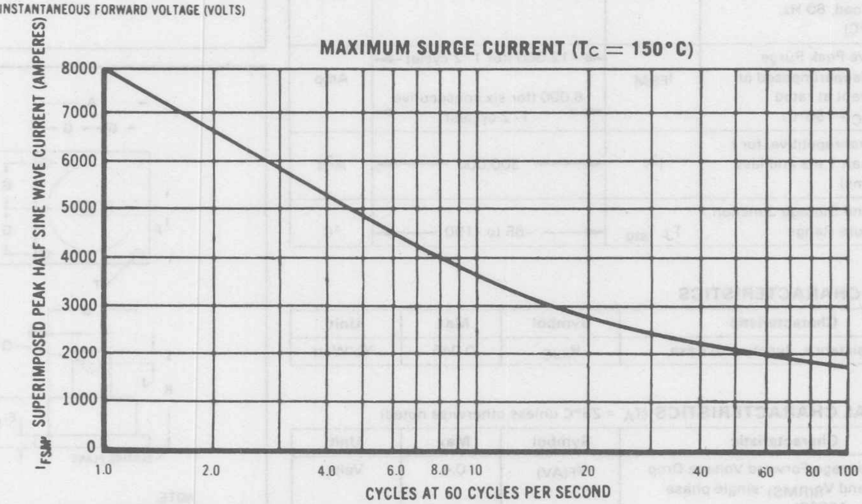
FORWARD VOLTAGE CHARACTERISTICS



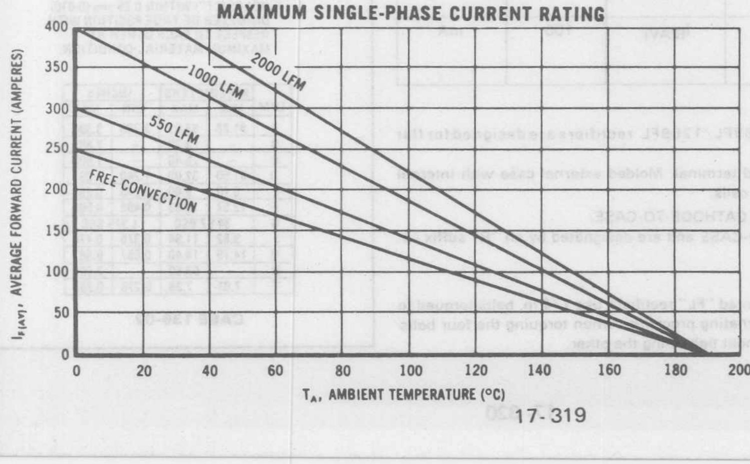
MAXIMUM FORWARD CURRENT versus MAXIMUM CASE TEMPERATURE



MAXIMUM SURGE CURRENT ($T_C = 150°C$)



MAXIMUM SINGLE-PHASE CURRENT RATING



CONDITIONS

8 x 8 x ¼ copper heat sink fin $\epsilon \geqq 0.9$ and mounted parallel to air flow. 180° conduction.

For 3 phase ratings multiply current scale by 0.85.

For 6 phase ratings multiply current scale by 0.60.

MOTOROLA

MR1265FL
MR1269FL

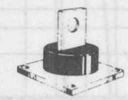
MULTI-CELL POWER RECTIFIERS

. . . designed for applications requiring low power dissipation and high inrush surge current.

A heavy copper base/heat sink provides low thermal resistance and lowest operating junction temperatures.

HIGH-CURRENT SILICON RECTIFIERS

650 AMPERE
300, 600 VOLTS
DIFFUSED JUNCTIONS



MAXIMUM RATINGS

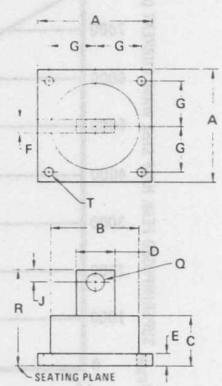
Rating	Symbol	MR1265	MR1269	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	300	600	Volts
Nonrepetitive Peak Reverse Voltage (one half-wave, single phase, 60 cycle peak)	V_{RSM}	400	720	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	210	420	Volts
Average Rectified Forward Current (single phase, resistive load, 60 Hz, $T_C = 150°C$)	I_O	← 650 →		Amp
Nonrepetitive Peak Surge Currents (superimposed on rated current at rated voltage, $T_C = 150°C$)	I_{FSM}	← 12,000 (for 1/2 cycle) → 8,000 (for six consecutive 1/2 cycles)		Amp
I^2t Rating (nonrepetitive, for t greater than 1 ms and less than 8.3 ms)	I^2t	← 300,000 →		A^2s
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← −65 to +190 →		°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	0.045	°C/Watt

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Max	Unit
Full Cycle Average Forward Voltage Drop (rated I_O and $V_{R(RMS)}$, single phase 60 Hz, $T_C = 150°C$)	$V_{F(AV)}$	0.4	Volts
Full Cycle Average Reverse Current (rated I_O and $V_{R(RMS)}$, single phase 60 Hz, $T_C = 150°C$)	$I_{R(AV)}$	100	mA



NOTE:
1. HOLES ("T") WITHIN 0.25 mm (0.010) DIAMETER OF TRUE POSITION WITH RESPECT TO EACH OTHER AT MAXIMUM MATERIAL CONDITION.

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	81.28	83.82	3.200	3.300
B	–	73.28	–	2.885
C	–	25.40	–	1.000
D	51.50	32.00	1.240	1.260
E	6.10	6.60	0.240	0.260
F	12.57	12.83	0.495	0.505
G	34.92 BSC		1.375 BSC	
J	9.52	11.94	0.375	0.470
Q	14.15	14.40	0.557	0.567
R	–	63.50	–	2.500
T	7.01	7.26	0.276	0.286

CASE 136-02

MECHANICAL CHARACTERISTIC

PACKAGE CONFIGURATION: MR1265FL/1269FL rectifiers are designed for flat mounting and have a solid lug terminal.

All units have a plated copper base and terminal. Molded external case with internal hermetically sealed, metallic case rectifier cells.

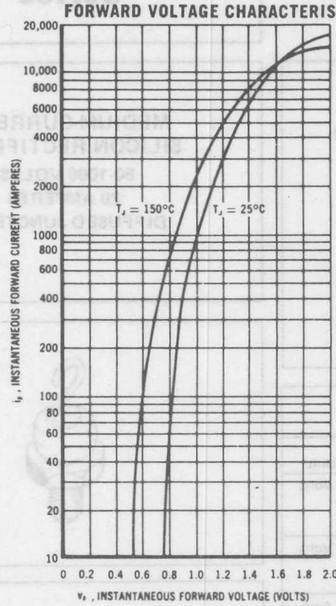
POLARITY: Standard polarity devices are CATHODE-TO-CASE.

Reverse polarity devices are ANODE-TO-CASE and are designated by an "R" suffix i.e. MR1265FLR.

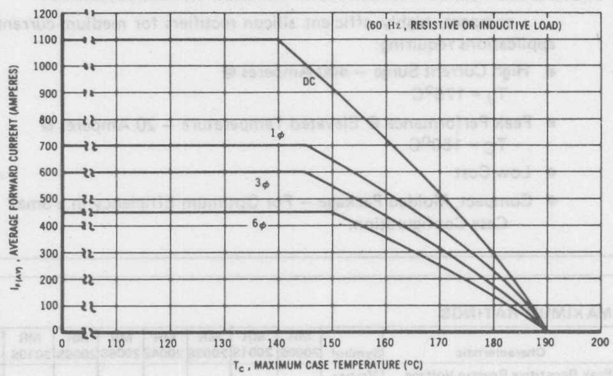
MOUNTING POSITION: Any.

MOUNTING BOLT TORQUES: Flat Mounted "FL" rectifiers use 1/4 in. bolts torqued to 60 in-lbs min., 80 in-lbs max. Use an alternating procedure when torquing the four bolts and do not tighten one bolt completely without tightening the other.

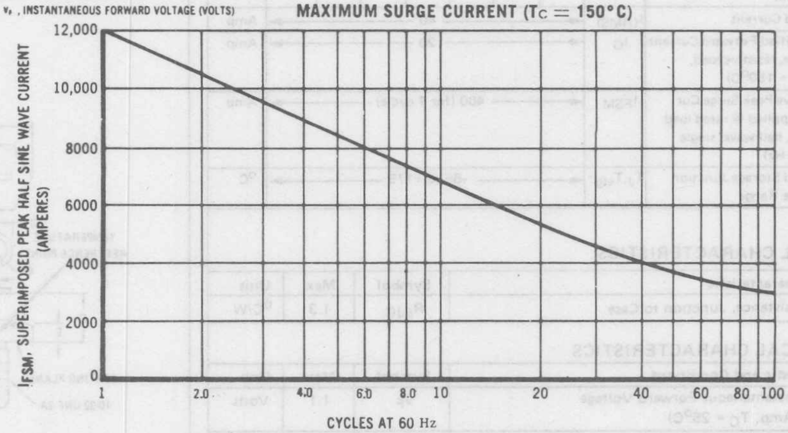
FORWARD VOLTAGE CHARACTERISTICS



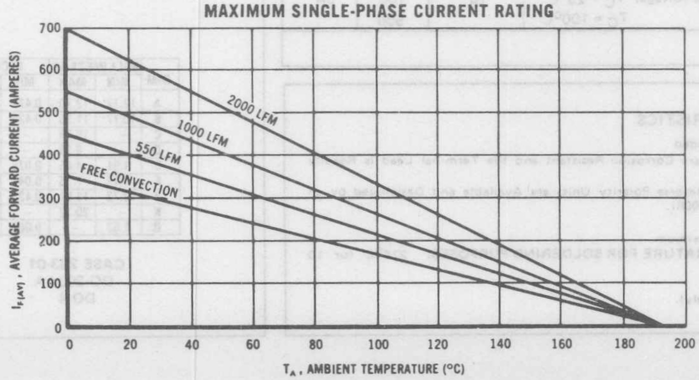
MAXIMUM FORWARD CURRENT versus MAXIMUM CASE TEMPERATURE



MAXIMUM SURGE CURRENT ($T_C = 150°C$)



MAXIMUM SINGLE-PHASE CURRENT RATING



CONDITIONS

10 x 10 x ¼ copper heat sink fin $\epsilon \geqq 0.9$ and mounted parallel to air flow, 180° conduction.

For 3 phase ratings multiply current scale by 0.85.

For 6 phase ratings multiply current scale by 0.60.

![MOTOROLA]

MOTOROLA

MR2000S Series

MEDIUM-CURRENT SILICON RECTIFIERS

. . . compact, highly efficient silicon rectifiers for medium-current applications requiring:

- High Current Surge — 400 Amperes @ $T_J = 175^oC$
- Peak Performance @ Elevated Temperature — 20 Amperes @ $T_C = 150^oC$
- Low Cost
- Compact, Molded Package — For Optimum Efficiency in a Small Case Configuration.

MEDIUM-CURRENT SILICON RECTIFIERS

50-1000 VOLTS
20 AMPERES
DIFFUSED JUNCTION

MAXIMUM RATINGS

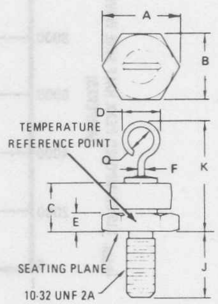
Characteristic	Symbol	MR 2000S	MR 2001S	MR 2002S	MR 2004S	MR 2006S	MR 2008S	MR 2010S	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 60 Hz peak)	V_{RSM}	60	120	240	480	720	960	1200	Volts
RMS Forward Current	$I_{(RMS)}$	← 40 →							Amp
Average Rectified Forward Current (Single phase, resistive load, 60 Hz, $T_C = 150^oC$)	I_O	← 20 →							Amp
Non-Repetitive Peak Surge Current (surge applied @ rated load conditions, half wave, single phase, 60 Hz)	I_{FSM}	← 400 (for 1 cycle) →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -65 to +175 →							^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.3	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic and Conditions	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage ($i_F = 63$ Amp, $T_C = 25^oC$)	v_F	1.1	Volts
Maximum Reverse Current (rated dc voltage) $T_C = 25^oC$ $T_C = 100^oC$	I_R	100 500	µA



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	12.12	12.70	0.477	0.500
B	10.77	11.10	0.424	0.437
C	–	10.29	–	0.405
D	–	6.35	–	0.250
E	1.91	4.45	0.075	0.175
F	1.19	1.35	0.047	0.053
J	10.72	11.51	0.422	0.453
K	–	20.32	–	0.800
Q	1.52	–	0.060	–

CASE 283-01
DO-203AA
DO-4

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded.
FINISH: All External Surfaces are Corrosion-Resistant and the Terminal Lead is Readily Solderable.
POLARITY: Cathode to Case (Reverse Polarity Units are Available and Designated by an "R" Suffix i.e., MR2000SR).
MOUNTING POSITIONS: Any
STUD TORQUE: 15 in. lbs. Maximum
MAXIMUM TERMINAL TEMPERATURE FOR SOLDERING PURPOSES: 275°C for 10 Seconds @ 3 Kg Tension.

WEIGHT: 6 Grams (Approximately).

FIGURE 1 – FORWARD VOLTAGE

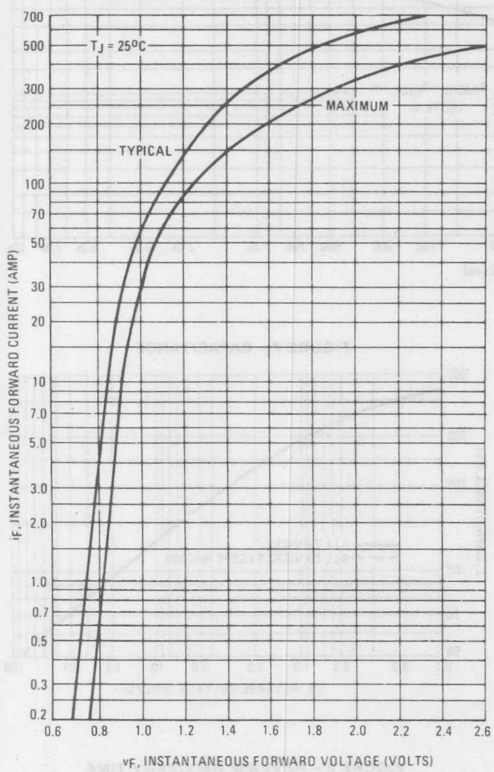


FIGURE 2 – NON-REPETITIVE SURGE CURRENT

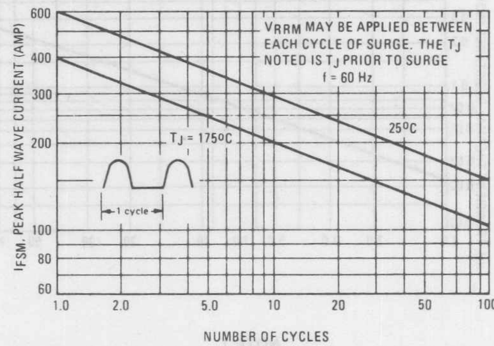


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

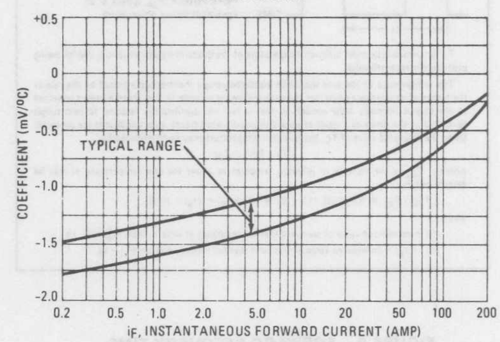


FIGURE 4 – CURRENT DERATING

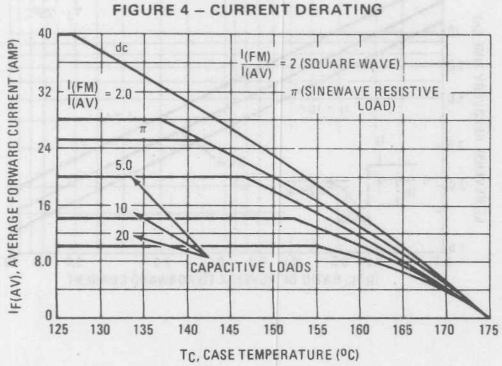


FIGURE 5 – FORWARD POWER DISSIPATION

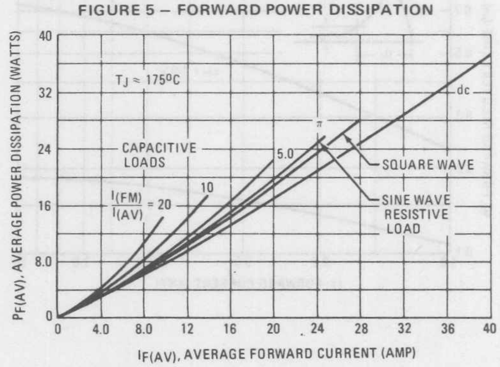
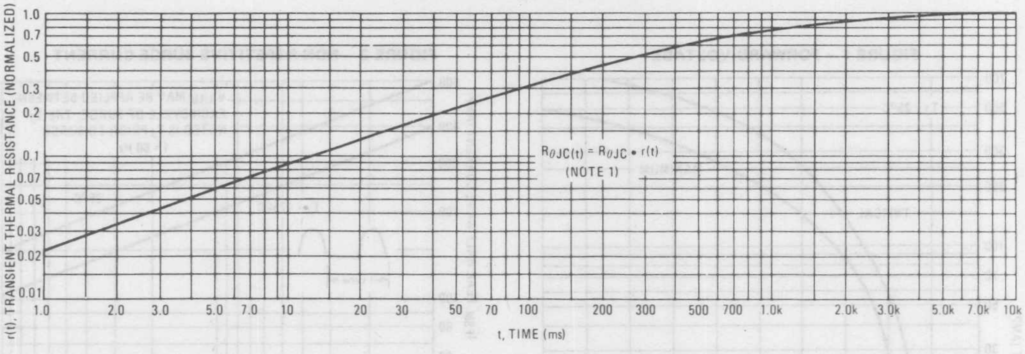
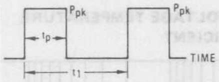


FIGURE 6 – THERMAL RESPONSE



NOTE 1



DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.,

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

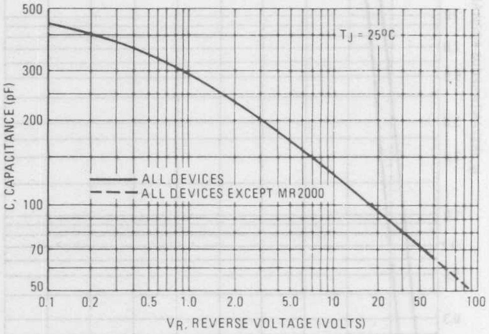


FIGURE 8 – FORWARD RECOVERY TIME

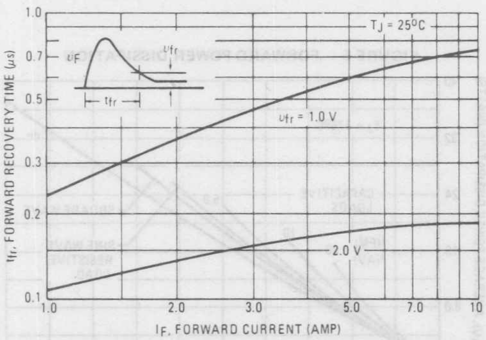


FIGURE 9 – REVERSE RECOVERY TIME

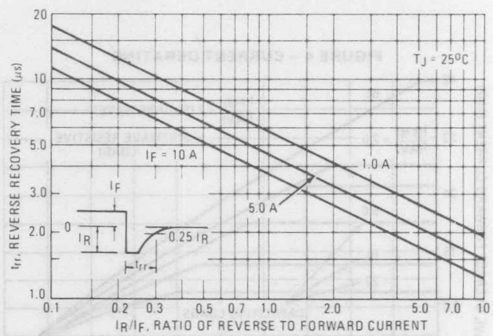
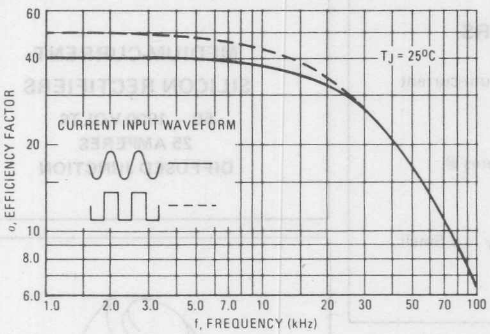
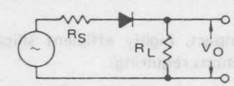


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY



RECTIFICATION EFFICIENCY NOTE

FIGURE 11 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\dfrac{V^2_{O(dc)}}{R_L}}{\dfrac{V^2_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2_{O(dc)}}{V^2_{O(ac)} + V^2_{O(dc)}} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assume lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\dfrac{V^2_m}{\pi^2 R_L}}{\dfrac{V^2_m}{4R_L}} \bullet 100\% = \frac{4}{\pi^2} \bullet 100\% = 40.6\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\dfrac{V^2_m}{2R_L}}{\dfrac{V^2_m}{R_L}} \bullet 100\% = 50\% \quad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 10.

It should be emphasized that Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_O with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

![MOTOROLA]

MOTOROLA

MR2500 Series

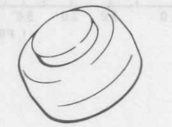
MEDIUM-CURRENT SILICON RECTIFIERS

. . . compact, highly efficient silicon rectifiers for medium-current applications requiring:

- High Current Surge – 400 Amperes @ T_J = 175°C
- Peak Performance @ Elevated Temperature – 25 Amperes @ T_C = 150°C
- Low Cost
- Compact, Molded Package – For Optimum Efficiency in a Small Case Configuration

MEDIUM-CURRENT SILICON RECTIFIERS

50 – 1000 VOLTS
25 AMPERES
DIFFUSED JUNCTION



MAXIMUM RATINGS

Characteristic	Symbol	MR 2500	MR 2501	MR 2502	MR 2504	MR 2506	MR 2508	MR 2510	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage (half wave, single phase, 60 Hz peak)	V_{RSM}	60	120	240	480	720	960	1200	Volts
Average Rectified Forward Current (Single phase, resistive load, 60 Hz, T_C = 150°C)	I_O	← 25 →							Amp
Non-Repetitive Peak Surge Current (surge applied @ rated load conditions, half wave, single phase, 60 Hz)	I_{FSM}	← 400 (for 1 cycle) →							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	← -65 to +175 →							°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case (Single Side Cooled)	$R_{\theta JC}$	1.0	°C/W

ELECTRICAL CHARACTERISTICS

Characteristics and Conditions	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage (i_F = 78.5 Amp, T_C = 25°C)	v_F	1.18	Volts
Maximum Reverse Current (rated dc voltage) T_C = 25°C T_C = 100°C	I_R	 100 500	μA

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded.

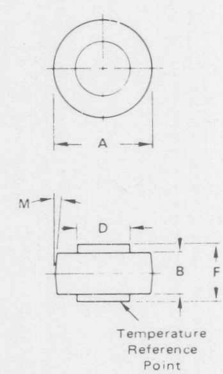
FINISH: All External Surfaces are Corrosion Resistant and the Contact Areas Readily Solderable.

POLARITY: Indicated by dot on Cathode Side

MOUNTING POSITIONS: Any

MAXIMUM TEMPERATURE FOR SOLDERING PURPOSES: 250°C

WEIGHT: 1.8 Grams (Approximately)



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	10.03	10.29	0.395	0.405
B	4.19	4.45	0.165	0.175
D	5.54	5.64	0.218	0.222
F	5.94	6.25	0.234	0.246
M	5° NOM		5° NOM	

CASE 193-03

FIGURE 1 – FORWARD VOLTAGE

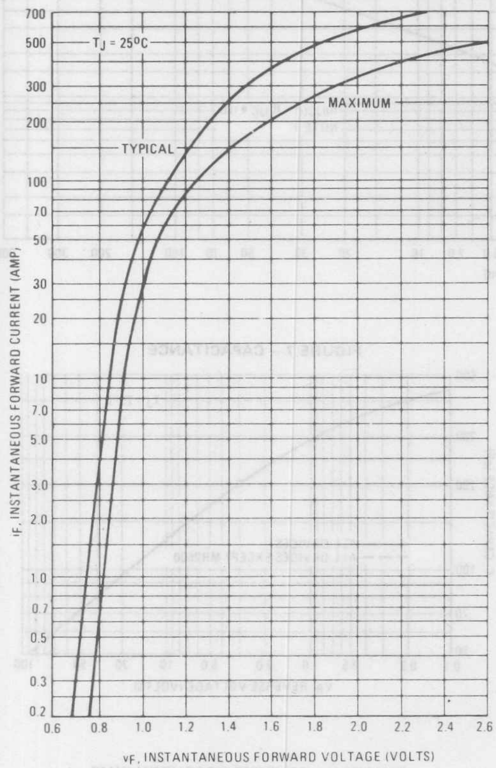


FIGURE 2 – NON-REPETITIVE SURGE CURRENT

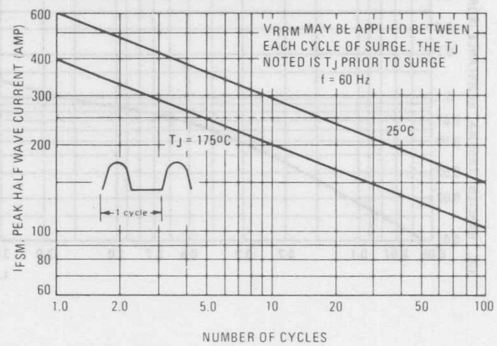


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

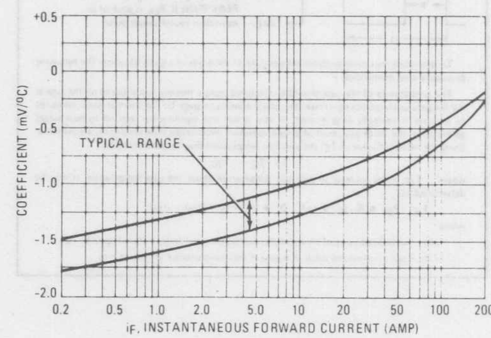


FIGURE 4 – CURRENT DERATING

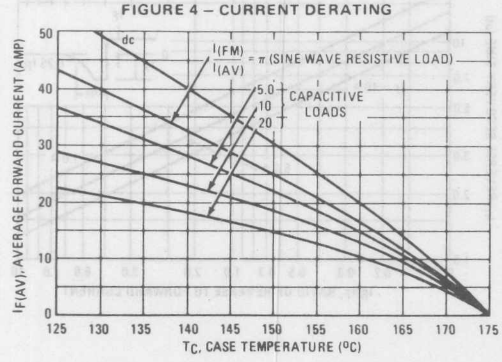


FIGURE 5 – FORWARD POWER DISSIPATION

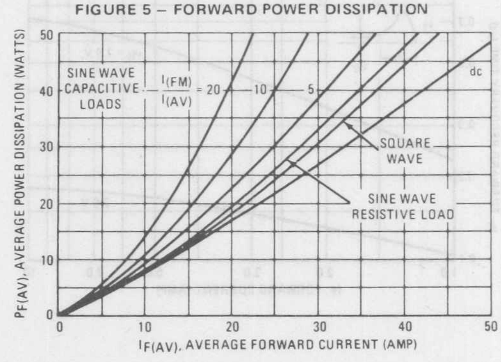
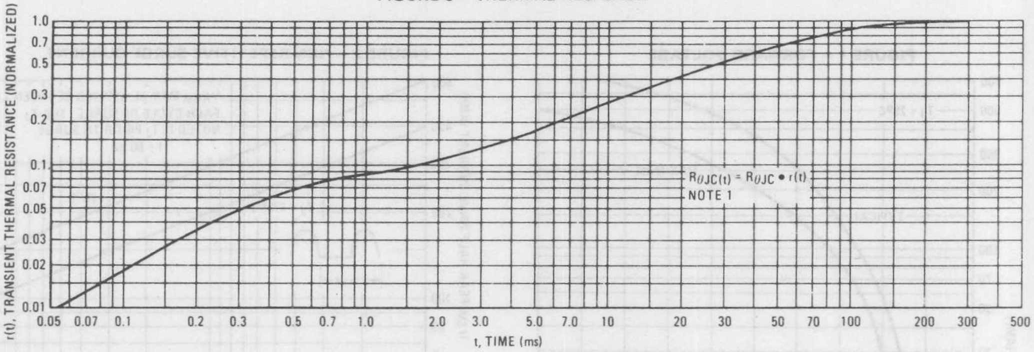
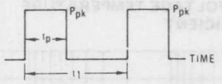


FIGURE 6 – THERMAL RESPONSE





DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.:

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

FIGURE 7 – CAPACITANCE

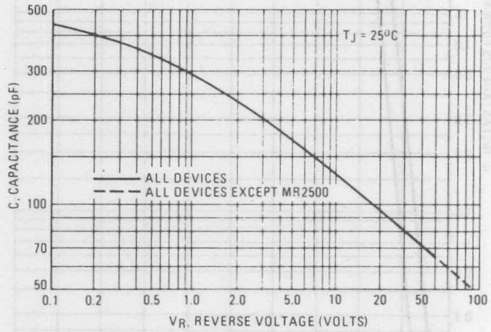


FIGURE 8 – FORWARD RECOVERY TIME

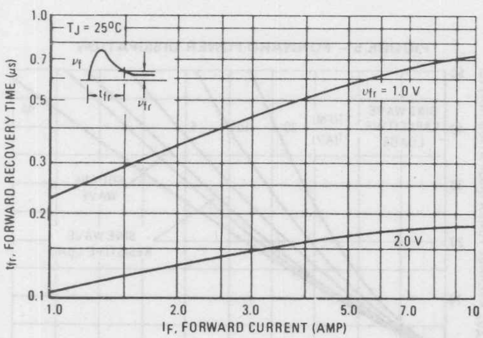


FIGURE 9 – REVERSE RECOVERY TIME

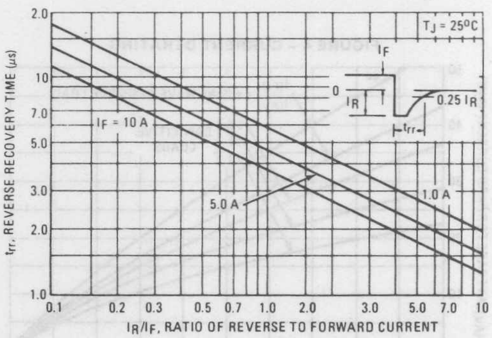
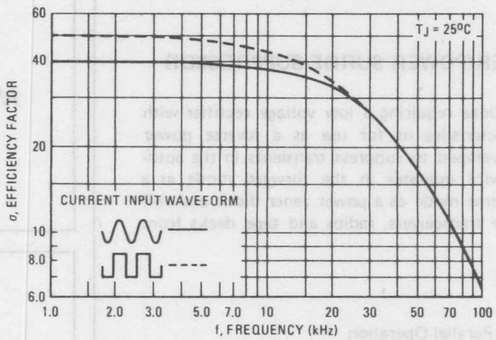
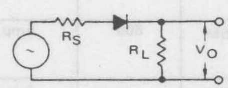


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY



RECTIFICATION EFFICIENCY NOTE

FIGURE 11 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\frac{V^2_O(dc)}{R_L}}{\frac{V^2_O(rms)}{R_L}} \bullet 100\% = \frac{V^2_O(dc)}{V^2_O(ac) + V^2_O(dc)} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assume lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\frac{V^2_m}{\pi^2 R_L}}{\frac{V^2_m}{4R_L}} \bullet 100\% = \frac{4}{\pi^2} \bullet 100\% = 40.6\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\frac{V^2_m}{2R_L}}{\frac{V^2_m}{R_L}} \bullet 100\% = 50\% \quad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 10.

It should be emphasized that Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_O with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

MOTOROLA

MR2525
MR2525R
MR2525L

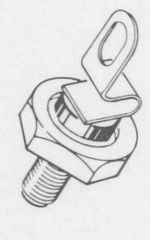
POWER RECTIFIER/POWER SURGE SUPPRESSOR

. . . designed for applications requiring a low voltage rectifier with reverse avalanche characteristics or for use as a reverse power transient suppressor. Developed to suppress transients in the automotive system, this device operates in the forward mode as a standard rectifier or reverse mode as a power zener diode and will protect expensive mobile transceivers, radios and tape decks from over-voltage conditions.

- High Power Capability
- Economical
- Increased Capacity by Parallel Operation
- Avalanche Voltage – 24 to 32 V

AVALANCHE RECTIFIER

6.0 AND 25 AMPERES



MR2525, MR2525R
CASE 296-03

MR2525L
CASE 194-01

MAXIMUM RATINGS

Rating	Symbol	Limit	Unit
DC Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	23	Volts
RMS Forward Current	$I_{(RMS)}$	94	Amp
Average Rectified Forward Current MR2525, R MR2525L (Single Phase, Resistive Load, $T_C = 150^oC$)	I_O	 25 6	Amp
Non-Repetitive Peak Forward Surge Current (Surge Applied at Rated Load Conditions, Halfwave, Single Phase 60 Hz)	I_{FSM}	600	Amp
Repetitive Peak Reverse Surge Current (Pulse Width = 10 ms, Duty Cycle ≤ 1.0 %, $T_C = 85^oC$) Exponential (See Figure 2) Square Wave (See Figure 1)	I_{RSM}	 62 40	Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +175	^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case MR2525, R	$R_{\theta JC}$	0.95	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Max	Unit
Instantaneous Forward Voltage (1) (i_F = 79 Amp, $T_J = 25^oC$)	v_F	–	1.1	Volts
Reverse Current (V_R = 20 Vdc, $T_C = 25^oC$) (V_R = 20 Vdc, $T_C = 100^oC$)	I_R	 – –	 50 300	μAdc
Breakdown Voltage (I_R = 100 mAdc, $T_C = 25^oC$)	BV	24	32	Volts
Breakdown Voltage (2) (I_R = 40 Amp, $T_C = 85^oC$)	BV_M	–	40	Volts

(1) Pulse Test: Pulse Width ≤ 300 μs, Duty Cycle ≤ 2.0%.
(2) Pulse Test: Pulse Width ≤ 10 ms, Duty Cycle ≤ 2.0%.

REPETITIVE REVERSE SURGE CURRENT

($T_C = 85^oC$, Duty Cycle $\leqslant$1.0%)

FIGURE 1 – SQUARE WAVE

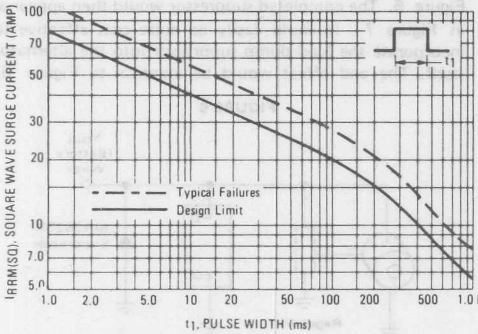
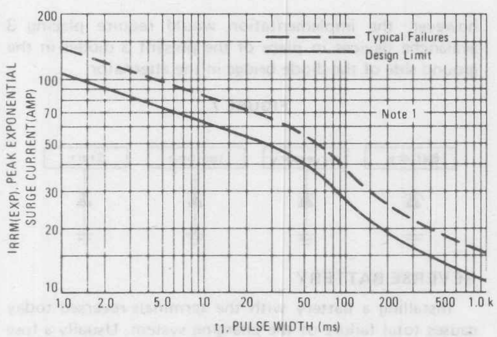
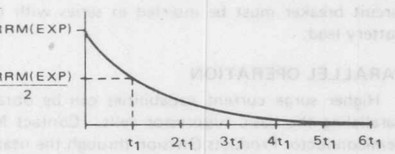


FIGURE 2 – EXPONENTIAL



NOTE 1

Time t_1 is at the half power point and is defined as follows:



The time constant of the exponential curve can be found by multiplying t_1 by 1.44.

TRANSIENTS IN THE AUTOMOTIVE ELECTRICAL SYSTEM

INTRODUCTION

The introduction of electronics into the automobile has brought with it the interesting sidelight of characterizing the automotive electrical system for transients.

Since most electro-mechanical systems exhibit a wear-out phenomenon as electrical stresses are increased, there has been no need to separately define transients from the normal load conditions. Any transient condition was simply accounted for by increasing contact ratings, etc. The introduction of semiconductors changes the picture since they exhibit a different sensitivity to transients. Semiconductors tend to have a black and white failure characteristic when exposed to transients in that no damage is caused below a certain level and total failure results above a certain level. Unfortunately these two levels are separate and the problem is further complicated by the fact that the energy tolerance of semiconductors is normally subject to a production distribution. This leaves solid state systems open to problems which are discovered only after many units are in the field.

SUMMARY OF TRANSIENTS

Transients in the automotive electrical system have widely varying energy levels occurring over widely varying times, but most become insignificant compared to the worst transient known as "Load Dump". Load dump happens when the battery becomes disconnected while the alternator is supplying charging current, or the disconnection of some other load with no battery present. Load dump transients generally are of 200 to 500 milliseconds duration, having an exponential decay from a worst case peak voltage of 80-120 volts. A clamped load dump, it should be noted, will be of considerably shorter duration.

Although the possibility of the battery becoming disconnected while the engine is running may seem remote, it is not reasonable this occurrence should result in the total failure of the electrical system of a car.

The following table lists some of the transients the automotive electronic designer must consider and should cause him to provide some level of protection.

Power Source	Available Transients
Battery Line	1. ±200 Volts for μseconds
	2. +Load Dump
Ignition Line and Accessory Line	1. -300 Volts for milliseconds
	2. ±200 Volts for μseconds
	3. +Load Dump

Note: All transients are exponential decay.

The voltages and times shown are reasonable values from many on-car measurements. Since the nonload-dump transients are of low energy, but high voltage, it is recommended they be clamped rather than blocked. It is imperative that source impedances also be known to allow proper selection of clamp devices.

STOPPING THE TRANSIENTS AT THE SOURCE

Figure 3 shows the most straight forward method of preventing large negative transients from disrupting the accessory and ignition busses. At the instant the switch is opened, the current flowing in the inductance will transfer to the diode producing about 1 volt negative on that particular buss. This condition will remain until the current in the inductance decays at a rate determined by the L/R time constant for the circuit. It can be shown that the peak currents and transient durations available in the car can easily be absorbed by a 1N4003 diode.

FIGURE 3

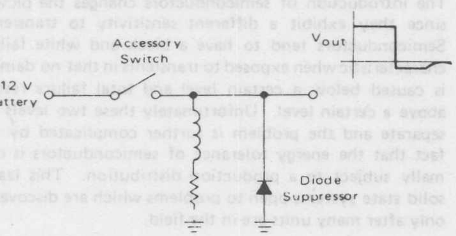
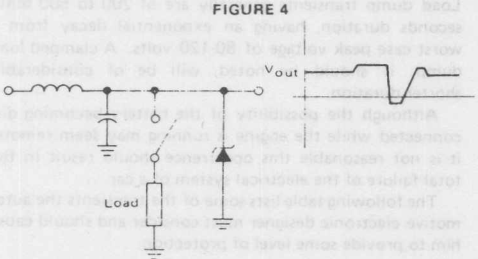


Figure 4 shows the most straight forward scheme for protecting against the series L-C type of transient. The forward biased diode action to protect the negative transient is similar to the action described for Figure 3. An avalanche device is required to clip off the positive portion.

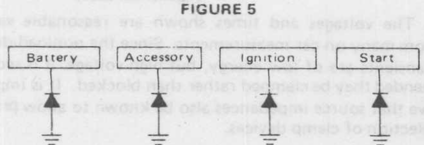
Just applying these two techniques and calling the result a master suppressor, overlooks the result of mutual coupling. Because of this effect, it becomes apparent that

FIGURE 4



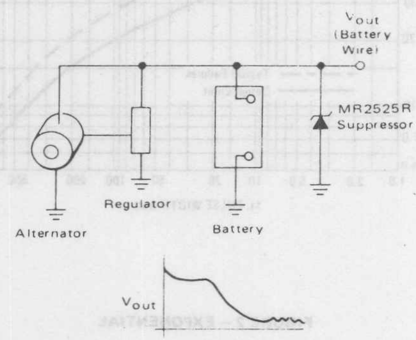
protecting against positive inductive transients at one spot is useless. Using the technique shown in Figure 4 to protect the various lines, would not be money well spent, since the same level of protection would still be required at each module anyway, due to mutual coupling. The best central suppressor for negative transients, then, is shown in Figure 5.

FIGURE 5



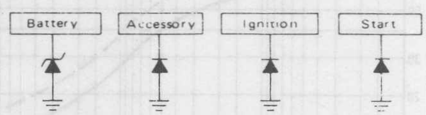
To complete the job, protection is needed against load dump. The easiest method is to simply clamp the output of the alternator with an avalanche device, as shown in Figure 6. The completed suppressor would then appear as in Figure 7. It could easily be more cost effective to incorporate the load dump suppressor into the alternator itself. The end effect would be identical to Figure 6,

FIGURE 6



however, the implementation would require placing 3 avalanche devices in place of the present 3 diodes in the ground side of the diode bridge in the alternator.

FIGURE 7



REVERSE BATTERY

Installing a battery with the terminals reversed today causes total failure of the charging system. Usually a fuse link fails, however, some cars suffer alternator failure. This condition is caused by a large current in-rush through the diode bridge which is forward biased during reverse battery condition. The master suppressor proposed in Figure 7 will suffer the same fate. While a suppressor can easily be devised, which will not drain current during −12 V condition, it is apparent that this defeats the purpose of the suppressor. In order to make this concept feasible, a circuit breaker must be inserted in series with the main battery lead.

PARALLEL OPERATION

Higher surge current capabilities can be obtained by paralleling the basic suppressor cells. Contact Motorola Semiconductor Products Division through the nearest sales office or authorized distributor for more information on number of cells required and package configurations available.

FIGURE 8 – MAXIMUM FORWARD VOLTAGE

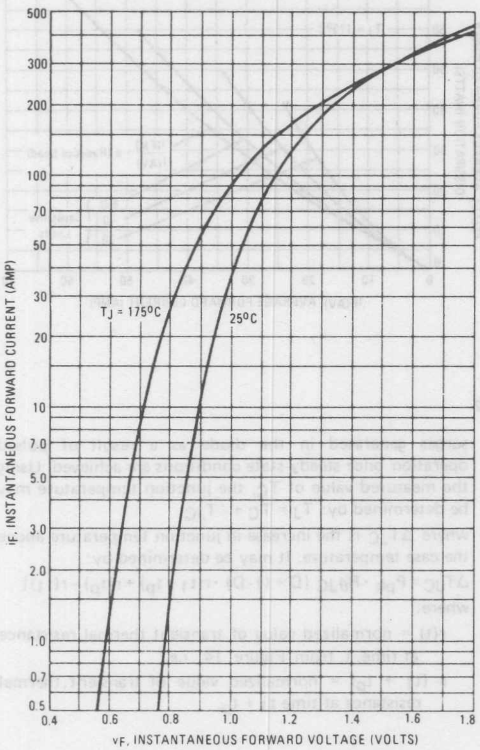


FIGURE 9 – MAXIMUM FORWARD NON-REPETITIVE SURGE CURRENT

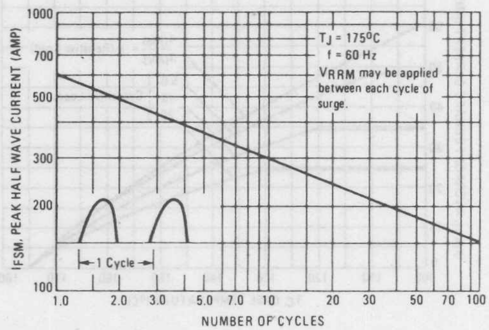


FIGURE 10 – TYPICAL FORWARD VOLTAGE TEMPERATURE COEFFICIENT

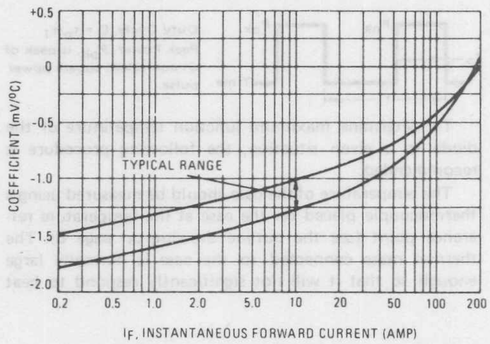
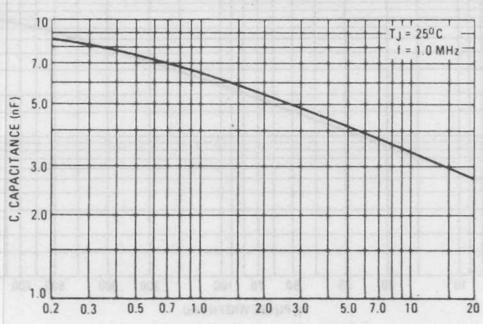


FIGURE 11 – CAPACITANCE



MR2525 AND MR2525R
FORWARD CURRENT DERATING DATA

FIGURE 12 – CURRENT DERATING

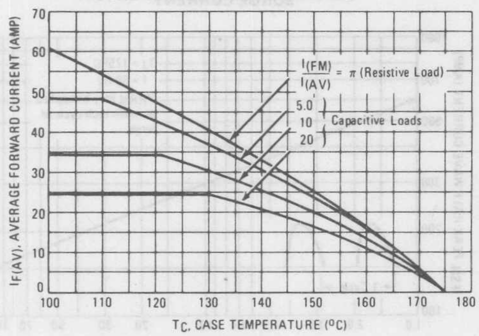
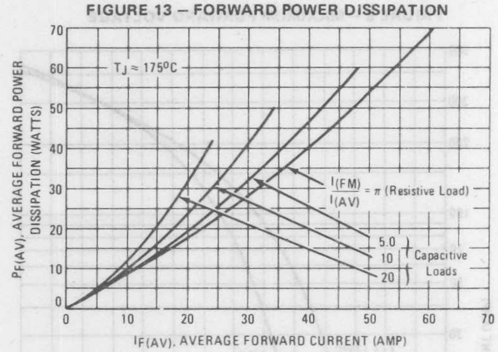
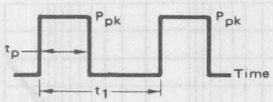


FIGURE 13 – FORWARD POWER DISSIPATION



NOTE 2



Duty Cycle, $D = t_p/t_1$
Peak Power, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended:

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 8). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady-state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by: $T_J = T_C + \Delta T_{JC}$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by:

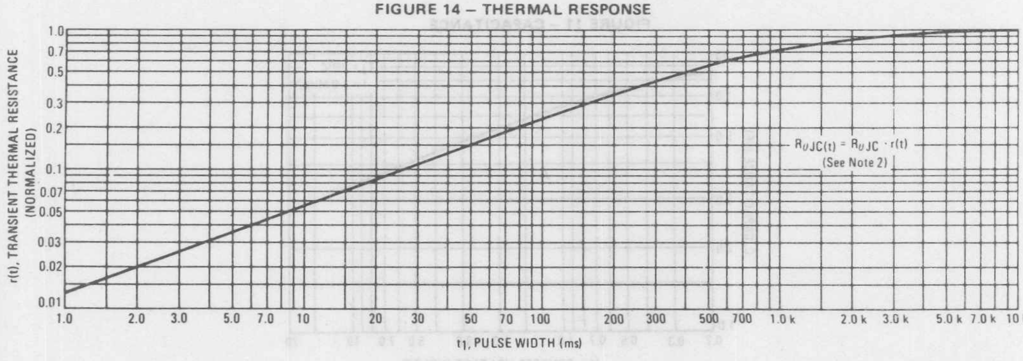
$\Delta T_{JC} = P_{pk} \cdot R_{\theta JC}\,[D + (1 - D) \cdot r(t_1 + t_p) + r(t_p) - r(t_1)]$

where:

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 14, i.e.,

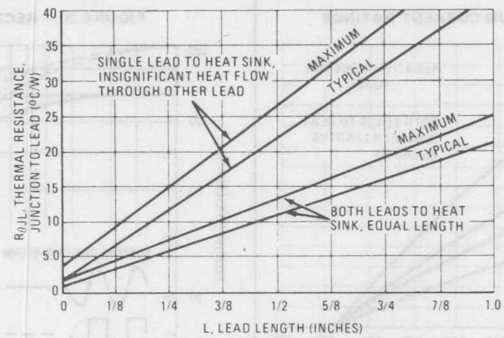
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 14 – THERMAL RESPONSE



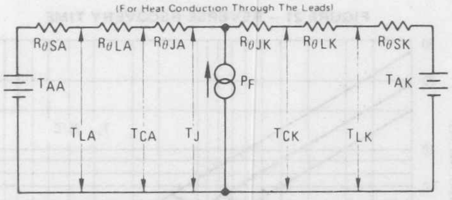
MR2525L
FORWARD CURRENT DERATING DATA

FIGURE 15 – STEADY STATE THERMAL RESISTANCE



NOTE 3

THERMAL CIRCUIT MODEL
(For Heat Conduction Through The Leads)



Use of the above model permits junction to lead thermal resistance for any mounting configuration to be found. Lowest values occur when one side of the rectifier is brought as close as possible to the heat sink as shown below. Terms in the model signify:

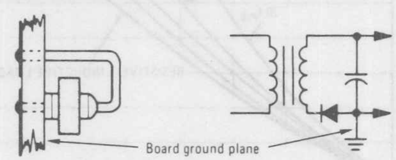
T_A	Ambient Temperature	$R_{\theta S}$	Thermal Resistance, Heat Sink to Ambient
T_L	Lead Temperature	$R_{\theta L}$	Thermal Resistance, Lead to Heat Sink
T_C	Case Temperature	$R_{\theta J}$	Thermal Resistance, Junction to Case
T_J	Junction Temperature	P_F	Power Dissipation

(Subscripts A and K refer to anode and cathode sides respectively.)

Values for thermal resistance components are:
$R_{\theta L}$ = 40°C/W/IN. Typically and 44°C/W/IN Maximum
$R_{\theta J}$ = 2°C/W Typically and 4°C/W Maximum

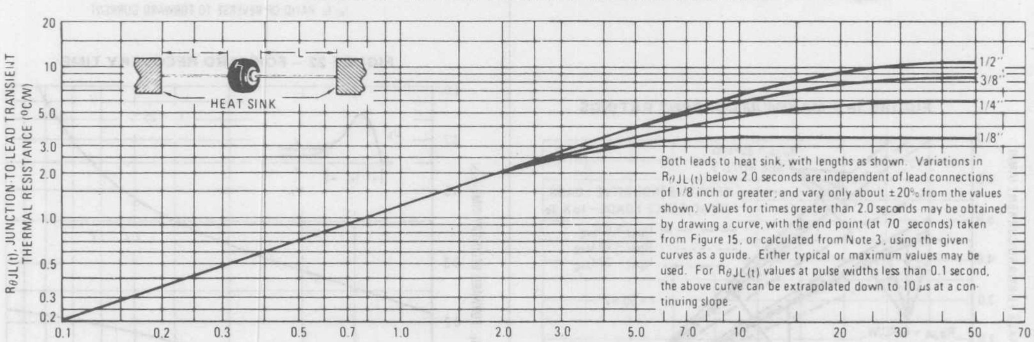
Since $R_{\theta J}$ is so low, measurements of the case temperature, T_C, will be approximately equal to junction temperature in practical lead mounted applications. When used as a 60 Hz rectifier, the slow thermal response holds $T_{J(PK)}$ close to $T_{J(AVG)}$. Therefore maximum lead temperature may be found from: $T_L = 175° - R_{\theta JL}\ P_F$. P_F may be found from Figure 18.

The recommended method of mounting to a P.C. board is shown on the sketch, where $R_{\theta JA}$ is approximately 25°C/W for a 1-1/2" x 1-1/2" copper surface area. Values of 40°C/W are typical for mounting to terminal strips or P.C. boards where available surface area is small.



Recommended mounting for half wave circuit

FIGURE 16 – TYPICAL TRANSIENT THERMAL RESISTANCE



MR2525L (continued)

FIGURE 17 – MAXIMUM CURRENT RATINGS

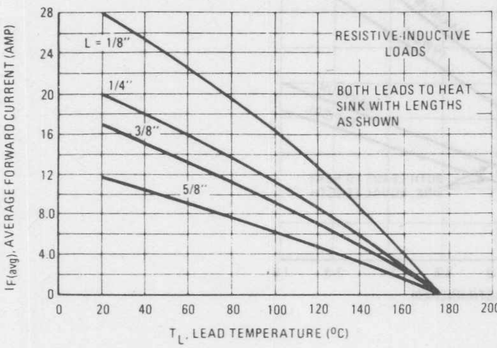


FIGURE 18 – POWER DISSIPATION

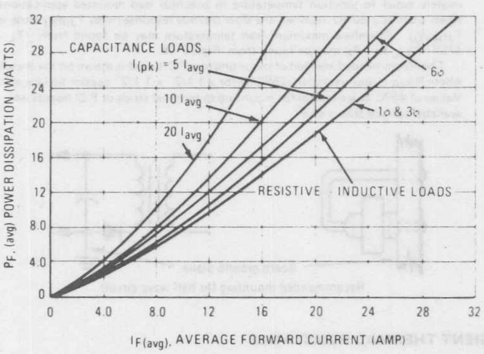
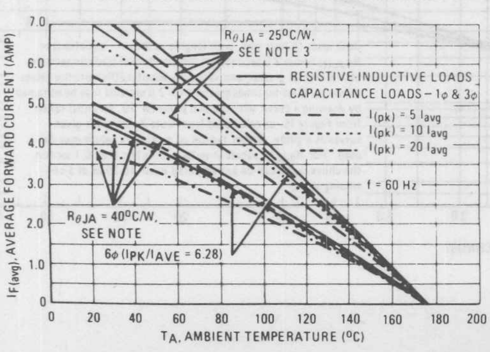


FIGURE 19 – MAXIMUM CURRENT RATINGS



MR2525, R, L
TYPICAL DYNAMIC CHARACTERISTICS

FIGURE 20 – RECTIFICATION EFFICIENCY

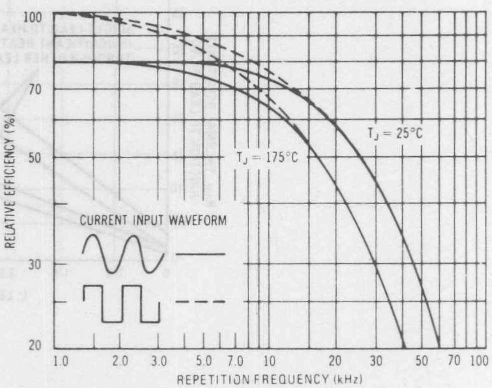


FIGURE 21 – REVERSE RECOVERY TIME

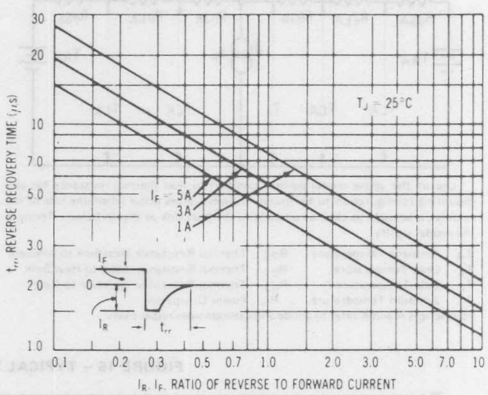
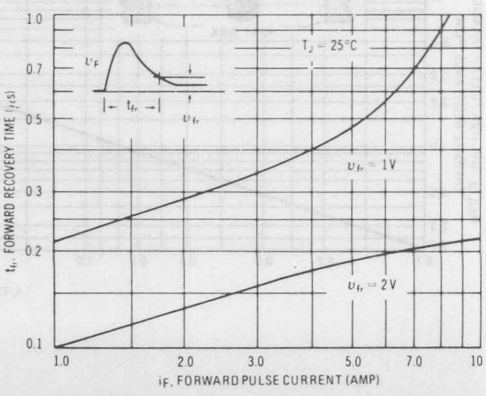
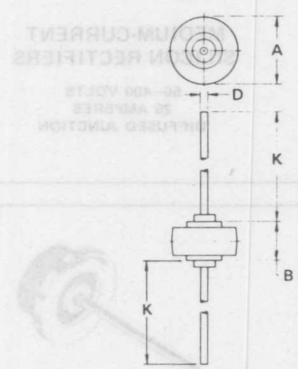


FIGURE 22 – FORWARD RECOVERY TIME



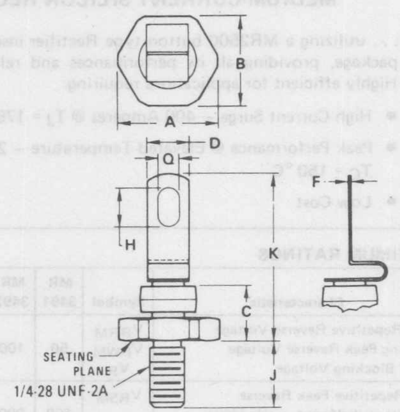
MR2525, MR2525R, MR2525L

OUTLINE DIMENSIONS



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	10.03	10.29	0.395	0.405
B	5.94	6.25	0.234	0.246
D	1.27	1.35	0.050	0.053
K	25.15	25.65	0.990	1.010

CASE 194-01



DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	18.29	–	0.720	–
B	16.99	17.48	0.669	0.688
C	–	10.67	–	0.420
D	–	8.38	–	0.330
F	0.46	0.56	0.018	0.022
H	7.62	8.13	0.300	0.320
J	10.72	11.51	0.422	0.453
K	–	30.48	–	1.200
Q	4.44	4.70	0.175	0.185

CASE 296-03

MECHANICAL CHARACTERISTICS: MR2525L

CASE: Void free, Transfer Molded

MAXIMUM LEAD TEMPERATURE FOR SOLDERING PURPOSES: 350°C 3/8" from case for 10 seconds at 50 lbs. tension

FINISH: All external surfaces are corrosion-resistant, leads are readily solderable

POLARITY: Indicated by diode symbol

WEIGHT: 2.5 Grams (approx)

MECHANICAL CHARACTERISTICS: MR2525, R

CASE: Void free, Transfer Molded

FINISH: All external surfaces are corrosion-resistant and the terminal lead is readily solderable

POLARITY: Standard polarity is cathode to case – MR2525. Reverse polarity is anode to case and is designated by an "R" suffix – MR2525R

MOUNTING POSITION: Any

STUD TORQUE: 20 in-lbs. maximum

MOTOROLA

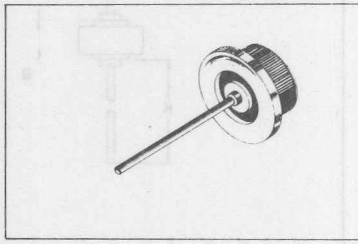
MEDIUM-CURRENT SILICON RECTIFIERS

. . . utilizing a MR2500 button type Rectifier inserted into a copper package, providing all its performances and reliability.
Highly efficient for applications requiring:

- High Current Surge – 400 Amperes @ T_J = 175 °C
- Peak Performance @ Elevated Temperature – 25 Amperes @ T_C = 150 °C
- Low Cost

MEDIUM-CURRENT SILICON RECTIFIERS

50–400 VOLTS
25 AMPERES
DIFFUSED JUNCTION



MAXIMUM RATINGS

Characteristic	Symbol	MR 3491	MR 3492	MR 3493	MR 3494	MR 3495	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	Volts
Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 50 Hz peak)	V_{RSM}	100	200	300	400	500	Volts
RMS Reverse Voltage	V_R	35	70	140	210	280	Volts
Average Rectified Forward Current (Single phase, resistive load, 50 Hz, T_C = 150 °C)	I_O	25					Amp
Non-Repetitive Peak Surge Current (Surge applied @ rated load conditions, half wave, single phase, 50 Hz	I_{FSM}	400 (for 1 cycle)					Amp
I^2t Rating (non-repetitive, for t greater than 1 ms and less than 10 ms)	I^2t	660					A^2 s (rms)
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–65 to +175					C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max.	Unit
Thermal Resistance, Junction to Case (Single Side Cooled)	$R_{\theta JC}$	1.2	C/W

ELECTRICAL CHARACTERISTICS

Characteristics and Conditions	Symbol	Max.	Unit
Maximum Instantaneous Forward Voltage (i_F = 78.5 Amp, T_C = 25 °C)	V_F	1.18	Volts
Maximum Reverse Current (rated dc voltage) T_C = 25 °C T_C = 100 °C	I_R	 100 500	μA

MECHANICAL CHARACTERISTICS

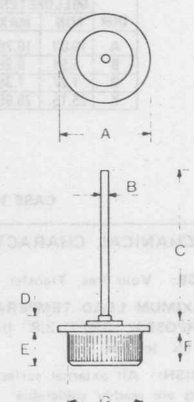
CASE: Void Free, Transfer Molded. Button inserted into a Copper frame

FINISH: All External Surfaces are Corrosion Resistant and the Contact Areas Readily Solderable

POLARITY: Cathode to case. For Reverse polarity parts, add "R" suffix. Ex: MR3491R

MOUNTING POSITIONS: Any

MAXIMUM TEMPERATURE FOR SOLDERING PURPOSES: 190 °C



DIM.	MILLIMETERS MIN.	MILLIMETERS MAX.	INCHES MIN.	INCHES MAX.
A	15.75	16.00	0.620	0.630
B	1.265	1.316	0.0498	0.0518
C	25.4	25.7	1.00	1.01
D	1.95	2.10	0.0768	0.0827
E	6.02	6.68	0.237	0.263
F	5.08		0.200	–
G	12.725	12.827	0.501	0.505

CASE 43-05

E-105 –

FIGURE 1 – FORWARD VOLTAGE

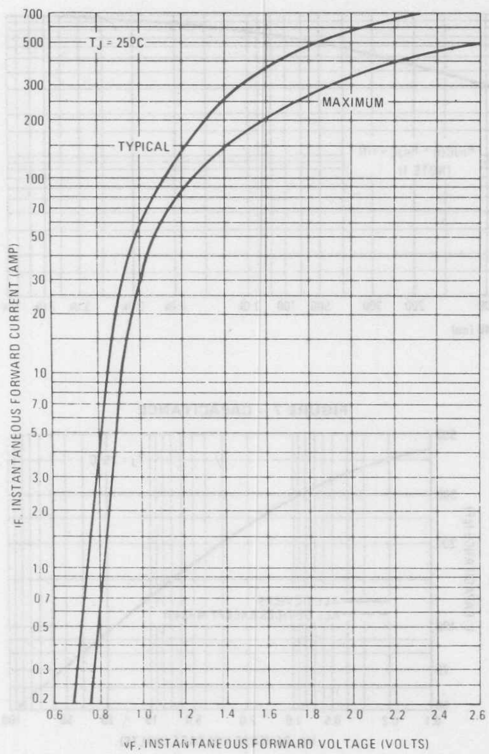


FIGURE 2 – NON-REPETITIVE SURGE CURRENT

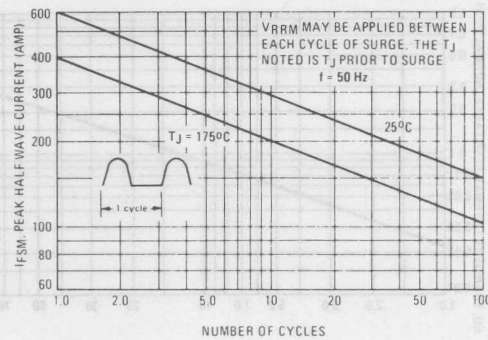


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

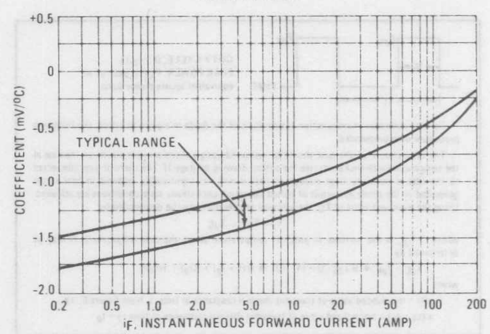


FIGURE 4 – CURRENT DERATING

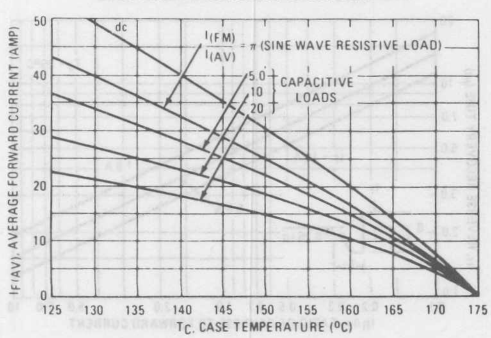


FIGURE 5 – FORWARD POWER DISSIPATION

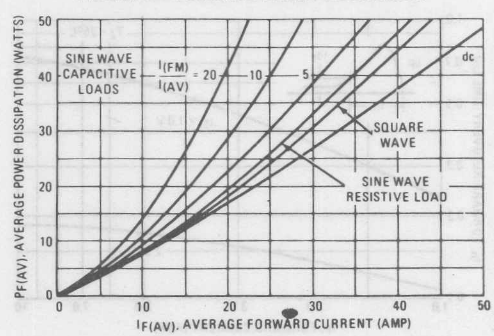
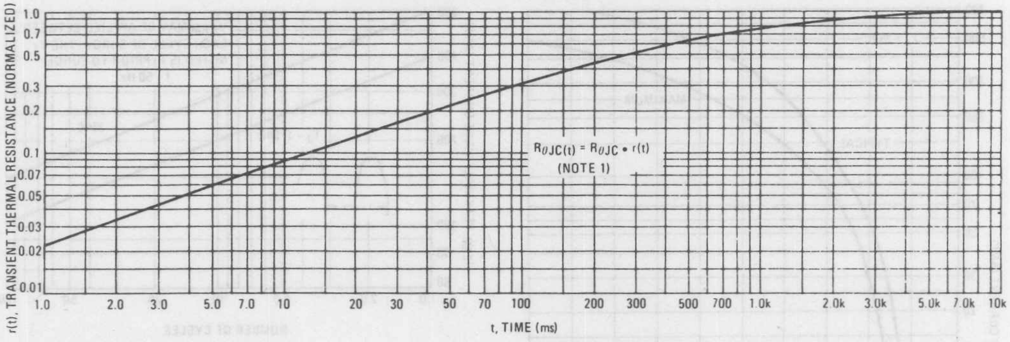
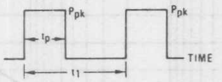


FIGURE 6 – THERMAL RESPONSE





DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by:

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.,
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

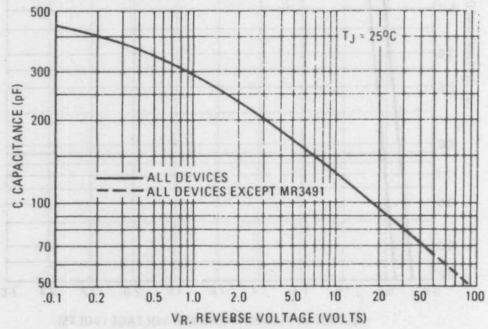


FIGURE 8 – FORWARD RECOVERY TIME

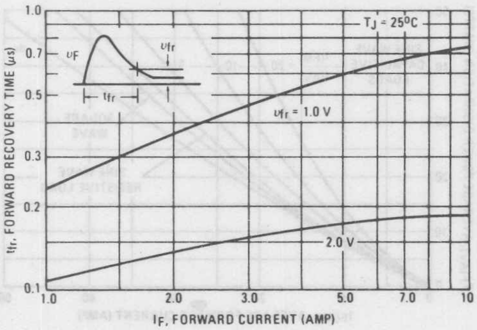


FIGURE 9 – REVERSE RECOVERY TIME

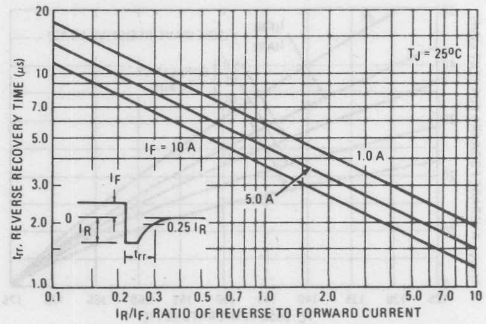
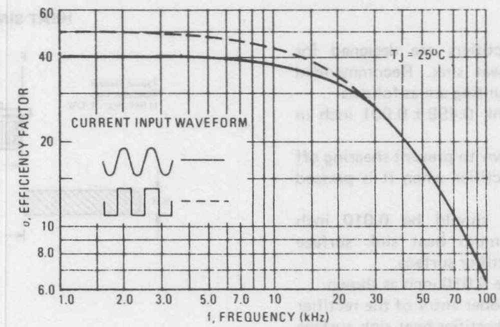
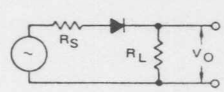


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY



RECTIFICATION EFFICIENCY NOTE

FIGURE 11 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\dfrac{V^2{}_O(dc)}{R_L}}{\dfrac{V^2{}_O(rms)}{R_L}} \bullet 100\% = \frac{V^2{}_O(dc)}{V^2{}_O(ac) + V^2{}_O(dc)} \bullet 100\% \qquad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assume lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\dfrac{V^2{}_m}{\pi^2 R_L}}{\dfrac{V^2{}_m}{4R_L}} \bullet 100\% = \frac{4}{\pi^2} \bullet 100\% = 40.6\% \qquad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\dfrac{V^2{}_m}{2R_L}}{\dfrac{V^2{}_m}{R_L}} \bullet 100\% = 50\% \qquad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 10.

It should be emphasized that Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_O with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

MOUNTING

Motorola MR3491 Series rectifiers are designed for press-fitted mounting in a heat sink. Recommended procedures for this type of mounting are as follows:

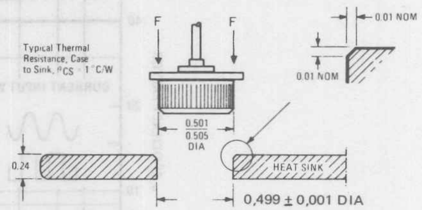
1. Drill a hole in the heat sink 0.499 ± 0.001 inch in diameter.
2. Break the hole edge as shown to prevent shearing off the knurled edge of the rectifier when it is pressed into the hole.
3. The depth of the break should be 0.010 inch maximum to retain maximum heat sink surface contact with the knurled rectifier surface.
4. Width of the break should be 0.010 inch as shown.

These procedures will allow proper entry of the rectifier knurled surface, provide good rectifier-heat sink surface contact, and assure reliable rectifier operation. If the break is made too deep, thereby reducing contact area for heat transfer, reliability of operation will be impaired.

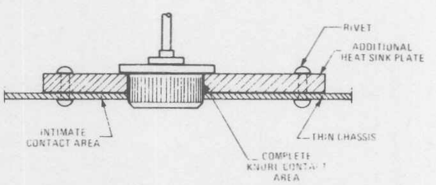
These devices can be mounted in a thin chassis by inserting the rectifier through an additional heat sink plate which is mounted in intimate contact with the upper side of the chassis. This provides additional contact area for the rectifier knurled edge, as well as additional heat sink capacity.

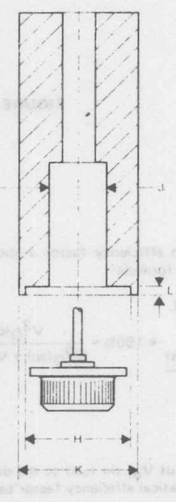
5. The pressing force will vary from 250 lbs (115 daN) to 1000 lbs (454 daN), depending on the heat-sink material used.
6. Pressing force must be appliedby a tool hereunder described:

HEAT SINK MOUNTING



THIN-CHASSIS MOUNTING





DIM	MILLIMETERS		INCHES	
	MIN.	MAX.	MIN.	MAX.
H	15.75	16.00	0.620	0.630
J	9.14	9.38	0.360	0.370
K	17.8	18.2	0.700	0.716
L	1.0	1.2	0.039	0.047

MOTOROLA

MR5005 MR5010
MR5020 MR5030
MR5040

INDUSTRIAL PRESSFIT SILICON POWER RECTIFIERS

. . . designed for use in all medium-current applications or for higher current industrial alternators and chassis mounted power supply rectifiers.

- 50 Amp @ $T_C = 150^oC$
- 600 Amp Surge Capability
- Reverse Polarity Available
- Rugged Construction

SILICON POWER RECTIFIERS

50-400 VOLTS
50 AMPERE

MAXIMUM RATINGS

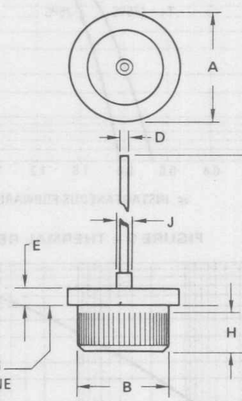
Rating	Symbol	MR5005	MR5010	MR5020	MR5030	MR5040	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	300	400	Volts
Non-Repetitive Peak Reverse Voltage	V_{RSM}	75	150	250	400	450	Volts
RMS Reverse Voltage	$V_{R(RMS)}$	35	70	140	210	280	Volts
Average Rectified Forward Current (Single phase, resistive load, $T_C = 150^oC$)	I_O	←		50		→	Amp
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions)	I_{FSM}	←		600		→	Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	←		-65 to +195		→	^oC

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	0.8	$^oC/W$

ELECTRICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Instantaneous Forward Voltage	v_F				Volts
($i_F = 157$ Amp, $T_J = 25^oC$)		–	1.10	1.18	
($i_F = 50$ Amp, $T_J = 25^oC$)		–	0.95	1.00	
Reverse Current (rated dc voltage)	I_R				mA
($T_C = 25^oC$)		–	0.05	0.2	
($T_C = 150^oC$)		–	1.0	2.0	



NOTES:
1. 50 TPI STRAIGHT KNURL.
2. POLARITY, INK MARKED ON PACKAGE

DIM	MILLIMETERS MIN	MILLIMETERS MAX	INCHES MIN	INCHES MAX
A	15.49	16.26	0.610	0.640
B	12.73	12.83	0.501	0.505
C	5.08	6.35	0.200	0.250
D	2.46	2.62	0.097	0.103
E	2.03	4.83	0.080	0.190
H	5.08	6.35	0.200	0.250
J	–	3.56	–	0.140
K	–	15.24	–	0.600

CASE 43-04

MECHANICAL CHARACTERISTICS

CASE: Welded hermetically sealed construction

FINISH: All external surfaces corrosion resistant, terminals readily solerable

WEIGHT: 9 grams (approx.)

POLARITY: Cathode connected to case (reverse polarity available denoted by Suffix R, i.e.: MR5030R)

MOUNTING POSITION: Any

FIGURE 1 – CURRENT DERATING

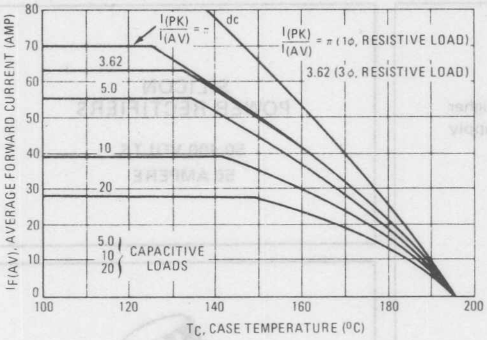


FIGURE 2 – FORWARD POWER DISSIPATION

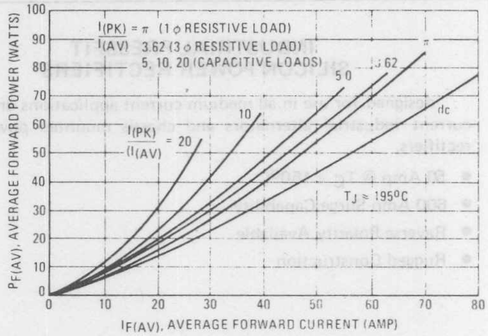


FIGURE 3 – MAXIMUM FORWARD VOLTAGE

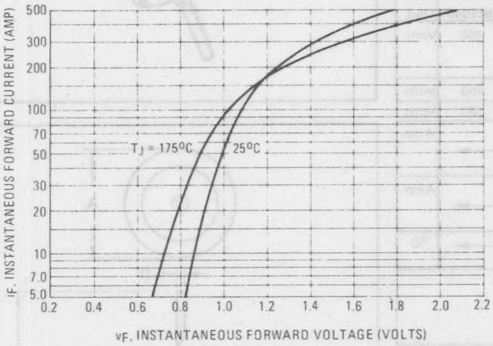


FIGURE 4 – MAXIMUM NON-REPETITIVE SURGE CAPABILITY

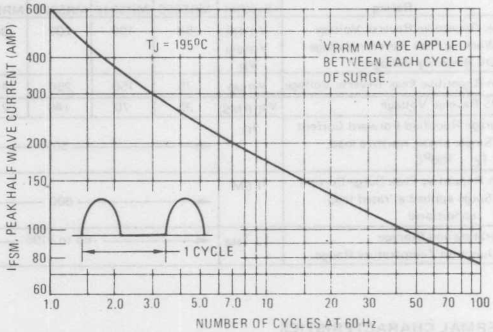
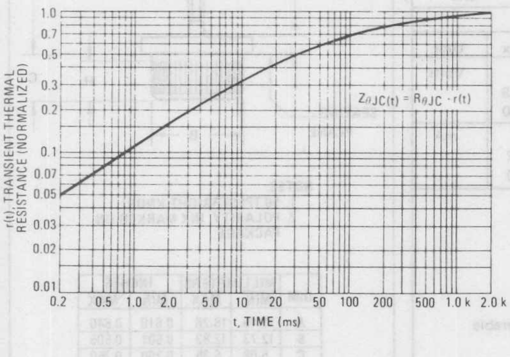
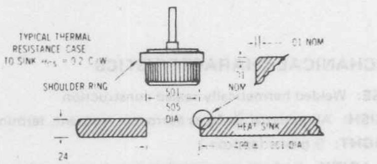


FIGURE 5 – THERMAL RESPONSE

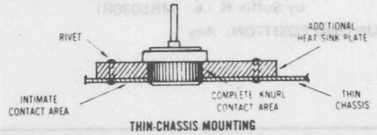


Recommended procedures for mounting are as follows:

1. Drill a hole in the heat sink 0.499 + 0.001 inch in diameter.
2. Break the hole edge as shown to provide a guide into the hole and prevent shearing off the knurled side of the rectifier.
3. The depth and width of the break should be 0.010 inch maximum to retain maximum heat sink surface contact.
4. To prevent damage to the rectifier during press-in, the pressing force should be applied only on the shoulder ring of the rectifier case as shown.
5. The pressing force should be applied evenly about the shoulder ring to avoid tilting or canting of the rectifier case in the hole during the press-in operation. Also, the use of a thermal lubricant such as D.C. 340 will be of considerable aid.



HEAT SINK MOUNTING



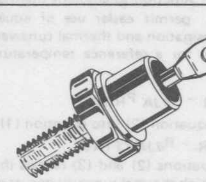
THIN-CHASSIS MOUNTING

MOTOROLA

SD 41

SCHOTTKY BARRIER RECTIFIERS

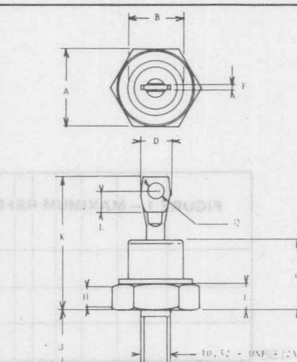
30 AMPERES
45 VOLTS



SWITCHMODE POWER RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact with ion implanted guard ring for transient protection. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremly Low V_F
- Low Stored Charge, Majority Carrier Conduction
- Lowest combined Power Loss
- High Surge Capacity



DIM	MILLIMETERS		INCHES	
	min.	max.	min.	max.
A	10,77	11,10	0,424	0,437
B				0,424
C	-	10,29		0,450
D			-	0,250
E	1,91	4,45	0,075	0,175
F	0,6	-	0,023	-
H	1,5	-	0,06	-
J	10,72	11,51	0,422	0,453
K	-	20,32	-	0,800
L	2,0	-	0,078	-
Q	1,5	-	0,060	

CASE 56
DO-4

MAXIMUM RATINGS

Rating	Symbol	SD 41	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	45 $T_C = 25^o$ C	Volts
Average Rectified Forward Current Square Wave, Rated V_R	$I_{F(AV)}$	30	Amp.
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions halfwave, single phase, 60 Hz)	I_{FSM}	600 (for 1 cycle)	Amp.
Operating and Storage Junction Temperature Range (Reverse voltage applied)	T_J, T_{stg}	–65 to +150	^{o}C
Peak Operating Junction Temperature (Forward Current applied)	$T_{J(pk)}$	175	^{o}C
Voltage Rate of change	dV/dt	700	V/us

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1,5	^{o}C/W

ELECTRICAL CHARACTERISTICS (T_C = 25^{o}C unless otherwise noted.)

Characteristic	Symbol	Min	Typ	Max	Unit
Maximum Instantaneous Forward Voltage (1) (I_F = 30 Amp.), $T_C = 125^o$ C	V_F	–	0,48	0,55	Volts
Maximum Instanteneous Reverse Current V_R = 35 V $T_C = 125^o$ C	I_R	– –	30	125	mA

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%.

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and terminal lead is readily solderable.

POLARITY: Cathode to Case

MOUNTING POSITION: Any

STUD TORQUE: 15 in. lb. Max.

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA} P_{F(AV)} - R_{\theta JA} P_{R(AV)} \qquad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (150°C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA} P_{R(AV)} \qquad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA} P_{F(AV)} \qquad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 150°C, when forward power is zero.

FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE

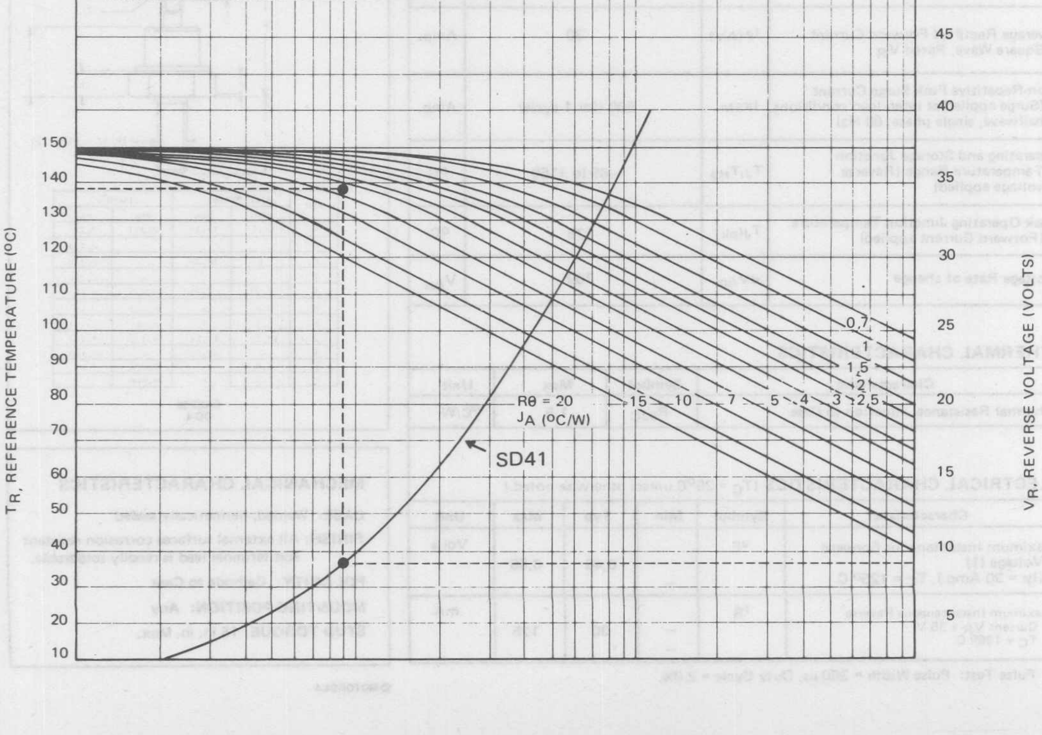


FIGURE 2 – TYPICAL FORWARD VOLTAGE

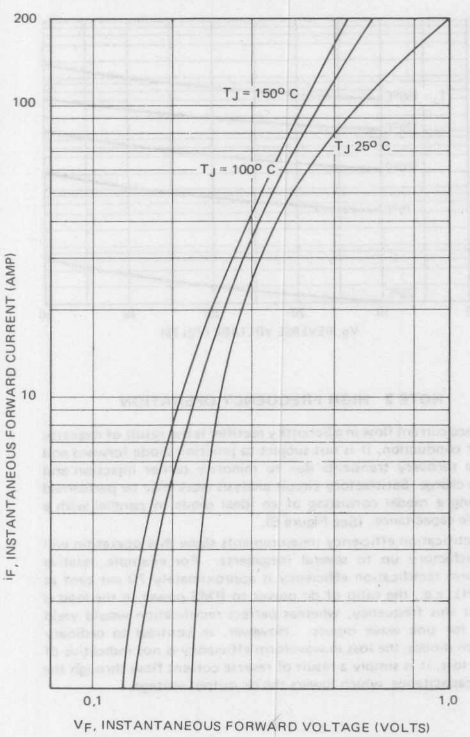


FIGURE 3 – MAXIMUM SURGE CAPACITY

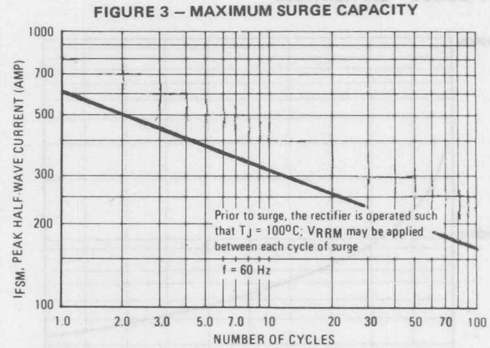


FIGURE 4 – FORWARD POWER DISSIPATION

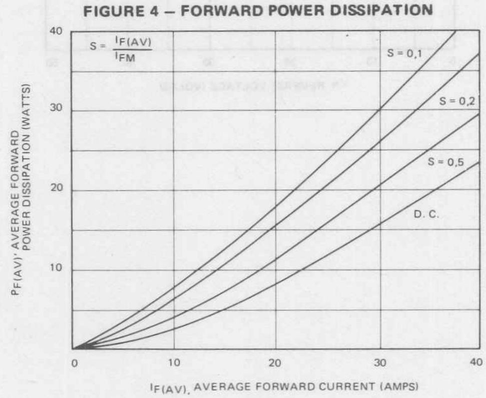


FIGURE 5 – THERMAL RESPONSE

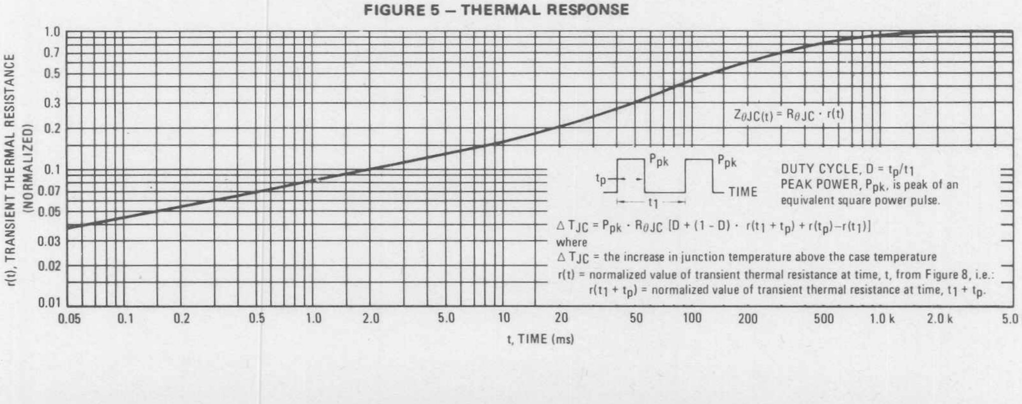


FIGURE 6 – CAPACITANCE

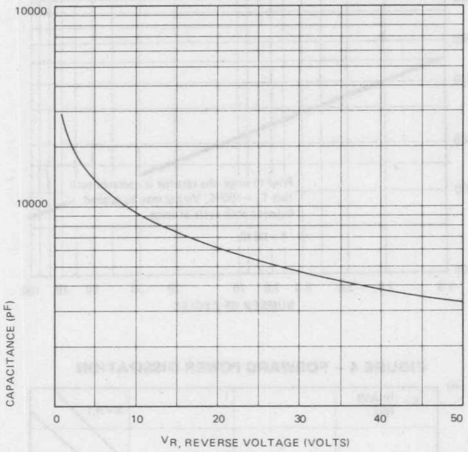
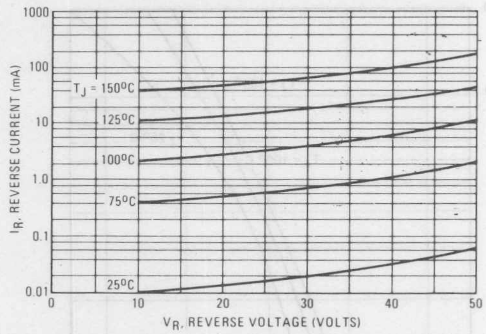


FIGURE 7 – TYPICAL REVERSE CURRENT



NOTE 2 HIGH FREQUENCY OPERATION

Since current flow in a Schottky rectifier is the result of majority carrier conduction, it is not subject to junction diode forward and reverse recovery transients due to minority carrier injection and stored charge. Satisfactory circuit analysis work may be performed by using a model consisting of an ideal diode in parallel with a variable capacitance. (See Figure 6).

Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

MOTOROLA

SD 51

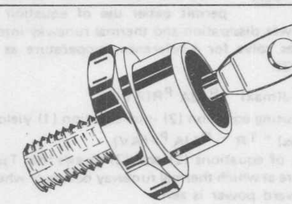
SCHOTTKY BARRIER RECTIFIERS

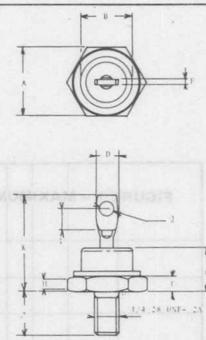
60 AMPERES
45 VOLTS

SWITCHMODE POWER RECTIFIERS

. . . employing the Schottky Barrier principle in a large area metal-to-silicon power diode. State of the art geometry features epitaxial construction with oxide passivation and metal overlap contact with ion implanted guard ring for transient protection. Ideally suited for use as rectifiers in low-voltage, high-frequency inverters, free wheeling diodes, and polarity protection diodes.

- Extremly Low V_F
- Low Stored Charge, Majority Carrier Conduction
- Lowest combined Power Loss
- High Surge Capacity





CASE 257
DO-5

DIM	MILLIMETERS		INCHES	
	min.	max	min	max
A	16,94	17,45	0,667	0,687
B	–	16,94	–	0,667
C	–	11,43	–	0,450
D	–	9,53	–	0,375
E	2,92	5,08	0,115	0,200
F	–	2,03	–	0,080
H	1,52	–	0,060	–
J	10,72	11,51	0,422	0,453
K	–	25,40	–	1,000
L	3,86	–	0,152	–
P	5,59	6,32	0,220	0,249
Q	3,56	4,45	0,140	0,175

NOTES:
1. Dimension "P" is diameter.
2. All JEDEC dimensions and notes apply.

MAXIMUM RATINGS

Rating	Symbol	SD 51	Unit
Peak Repetitive Reverse Voltage DC Blocking Voltage	V_{RRM} V_R	45 $T_C = 25^{o}$ C	Volts
Working Peak Reverse Voltage	V_{RWM}	35	Volts
Average Rectified Forward Current Square Wave, Rated V_R	$I_{F(AV)}$	60	Amp.
Voltage Rate of Change	dV/dt	700	$V/\mu s$
Non-Repetitive Peak Surge Current (Surge applied at rated load conditions halfware, single phase, 60 Hz)	I_{FSM}	800 (for 1 cycle)	Amp.
Operating and Storage Junction Temperature Range (Reverse voltage applied)	T_J, T_{stg}	–65 to +150	^{o}C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	175	^{o}C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Typ	Max.	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	0,7	0,9	$^{o}C/W$

ELECTRICAL CHARACTERISTICS

Characteristics	Symbol	Typ	Max.	Units
Instantaneous Forward Voltage (1) I_F = 60 Amp. $T_C = 25^{o}$ C $T_C = 125^{o}$ C I_F = 120 Amp. $T_C = 25^{o}$ C $T_C = 125^{o}$ C	V_F	 0,65 0,58 0,79 0,70	 0,70 0,60 0,87 0,84	Volts
Instantaneous Reverse Current, V_R = 35 V $T_C = 25^{o}$ C $T_C = 125^{o}$ C	I_R	 0,1 30	 50 200	mA

(1) Pulse test: pulse Width = 300 us, Duty cycle = 2%

MECHANICAL CHARACTERISTICS

CASE: Welded, hermetically sealed

FINISH: All external surfaces corrosion resistant and terminal lead is readily solderable.

POLARITY: Cathode to Case

MOUNTING POSITION: Any

STUD TORQUE: 25 in. lb. Max.

NOTE 1: DETERMINING MAXIMUM RATINGS

Reverse power dissipation and the possibility of thermal runaway must be considered when operating this rectifier at reverse voltages above 0.2 V_{RWM}. Proper derating may be accomplished by use of equation (1):

$$T_{A(max)} = T_{J(max)} - R_{\theta JA} P_{F(AV)} - R_{\theta JA} P_{R(AV)} \quad (1)$$

where

$T_{A(max)}$ = Maximum allowable ambient temperature

$T_{J(max)}$ = Maximum allowable junction temperature (150° C or the temperature at which thermal runaway occurs, whichever is lowest).

$P_{F(AV)}$ = Average forward power dissipation

$P_{R(AV)}$ = Average reverse power dissipation

$R_{\theta JA}$ = Junction-to-ambient thermal resistance

Figures 1 permit easier use of equation (1) by taking reverse power dissipation and thermal runaway into consideration. The figures solve for a reference temperature as determined by equation (2):

$$T_R = T_{J(max)} - R_{\theta JA} P_{R(AV)} \quad (2)$$

Substituting equation (2) into equation (1) yields:

$$T_{A(max)} = T_R - R_{\theta JA} P_{F(AV)} \quad (3)$$

Inspection of equations (2) and (3) reveals that T_R is the ambient temperature at which thermal runaway occurs or where T_J = 150° C. when forward power is zero.

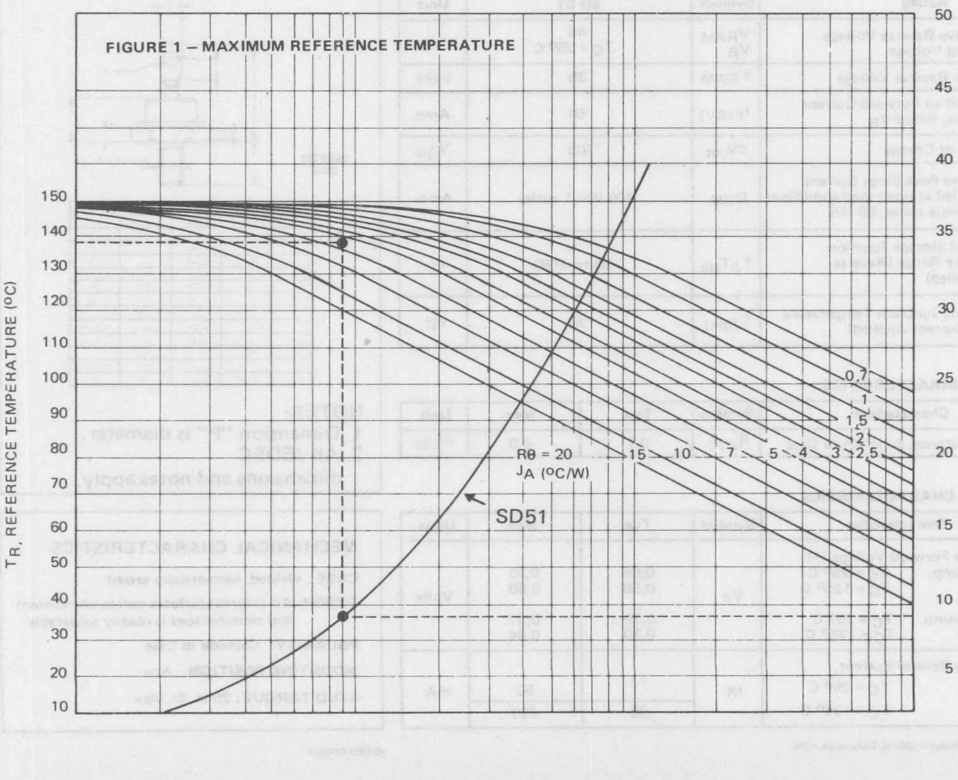


FIGURE 1 – MAXIMUM REFERENCE TEMPERATURE

FIGURE 2 – TYPICAL FORWARD VOLTAGE

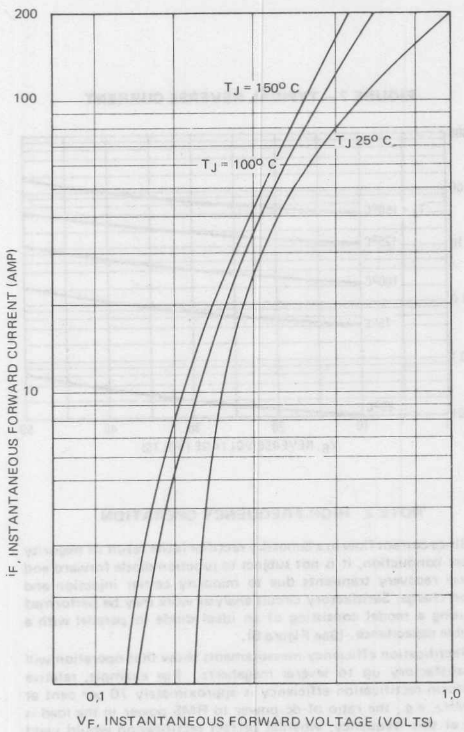


FIGURE 3 – MAXIMUM SURGE CAPACITY

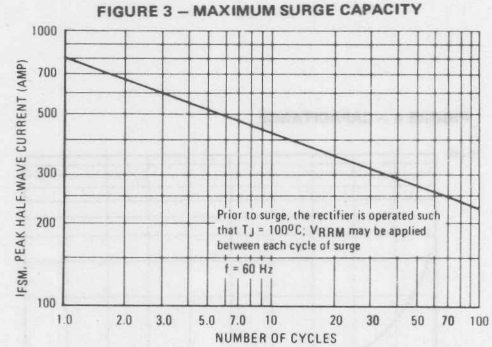


FIGURE 4 – FORWARD POWER DISSIPATION

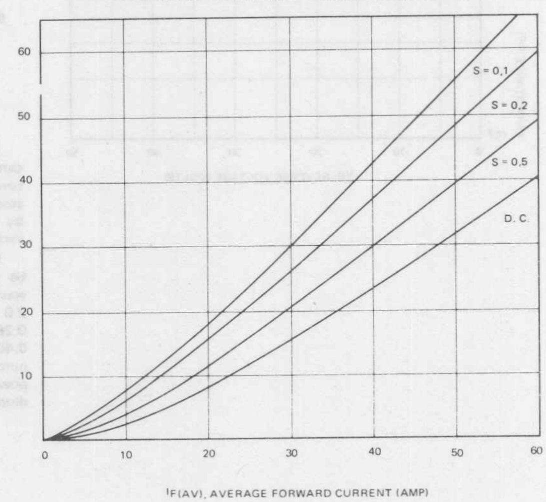


FIGURE 5 – THERMAL RESPONSE

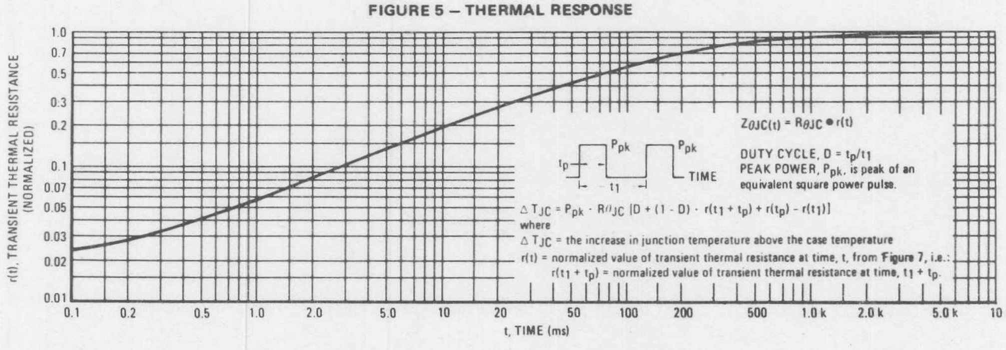


FIGURE 6 – CAPACITANCE

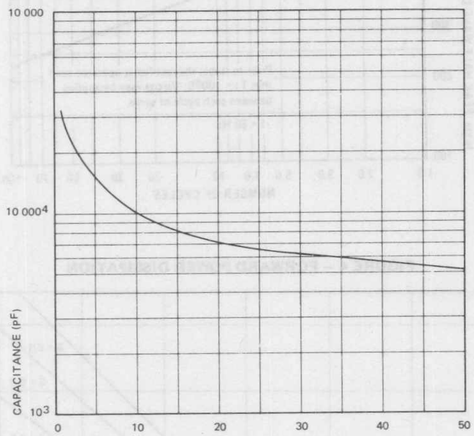
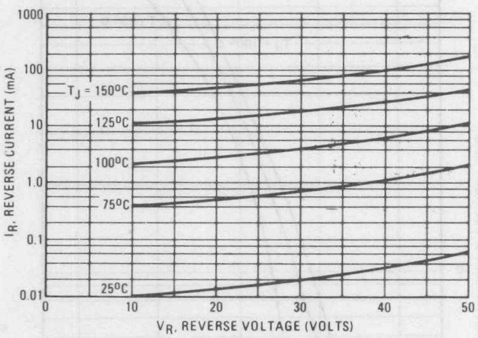


FIGURE 7 – TYPICAL REVERSE CURRENT



NOTE 2 HIGH FREQUENCY OPERATION

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Rectification efficiency measurements show that operation will be satisfactory up to several megahertz. For example, relative waveform rectification efficiency is approximately 70 per cent at 2.0 MHz, e.g., the ratio of dc power to RMS power in the load is 0.28 at this frequency, whereas perfect rectification would yield 0.406 for sine wave inputs. However, in contrast to ordinary junction diodes, the loss in waveform efficiency is not indicative of power loss; it is simply a result of reverse current flow through the diode capacitance, which lowers the dc output voltage.

MOTOROLA

SD 241

PRODUCT PREVIEW DATA SHEET

SCHOTTKY BARRIER RECTIFIERS

30 AMPERES
45 VOLTS

Switchmode Power Rectifiers

. . . using the Schottky Barrier principle with a platinum barrier metal. These state-of-the-art devices have the following features:

- Dual diode construction
- Guarding for stress protection
- Low V_f
- 150° C Operating Junction Temperature

MAXIMUM RATINGS PER DIODE

Rating	Symbol	SD 241	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	45	Volts
Average Rectified Forward Current (Rated V_R) $T_c = 95°C$	I_O	30	Amp
Non-repetitive Peak Surge Current (Surge applied at rated load conditions, halfwave, single phase, 60 Hz)	I_{FSM}	400	Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +150	°C
Peak Operating Junction Temperature (Forward Current Applied)	$T_{J(pk)}$	175	°C
Voltage Rate of Change (Rated V_R)	dv/dt	1000	v/μs

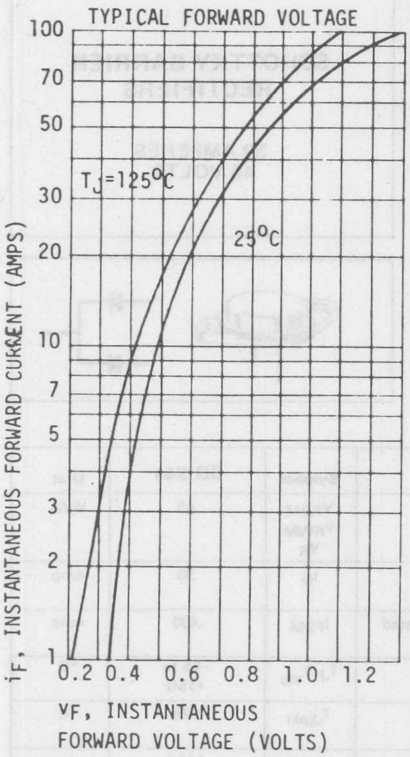
THERMAL CHARACTERISTICS PER DIODE

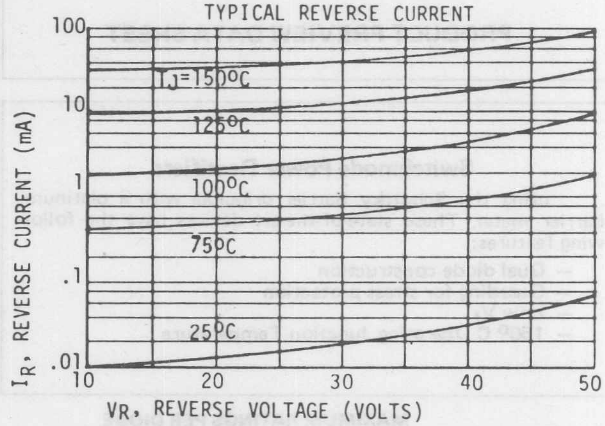
Characteristic	Symbol	max	Unit
Thermal Resistance, Junction to Case	$R_{\theta JC}$	1.4	°C/W

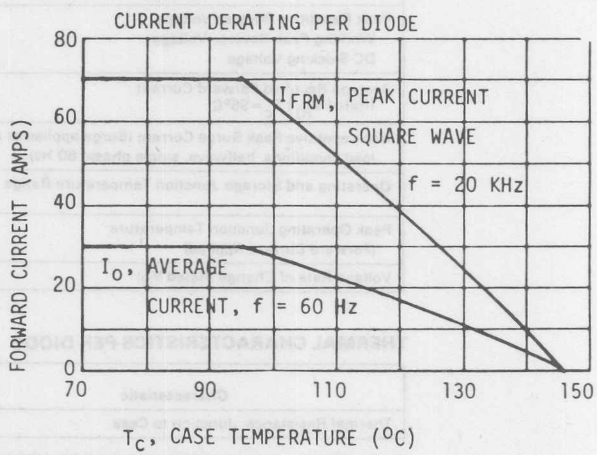
ELECTRICAL CHARACTERISTICS PER DIODE

Characteristic	Symbol	max	Unit
Maximum Instantaneous Forward Voltage (1) (I_F = 10 Amp, T_C = 125°C) (I_F = 20 Amp, T_C = 125°C)	v_F	 0.47 0.60	Volts
Maximum Instantaneous Reverse Current (1) (Rated dc Voltage, T_C = 125°C)	i_R	100 $V_R = 35V$	mA
Capacitance	C_t	2000	pF

(1) Pulse Test: Pulse Width = 300 μs, Duty Cycle = 2.0%

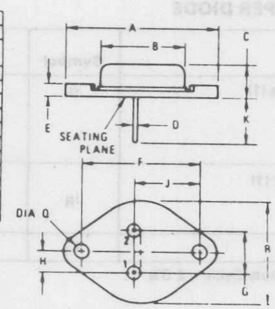






DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	-	39 37	-	1 550
B	-	21 08	-	0 830
C	6 35	7 62	0 250	0 300
D	0 99	1 09	0 039	0 043
E	-	3 43	-	0 135
F	29 90	30 40	1 177	1.197
G	10 67	11 18	0 420	0 440
H	5 33	5 59	0 210	0 220
J	16 64	17 15	0 655	0 675
K	11 18	12 19	0 440	0 480
Q	3 84	4 09	0 151	0 161
R	-	26 67	-	1 050

CASE 11 01
TO-3



CATHODES TO CASE

MOTOROLA

TRA 0750 SERIES

MEDIUM-CURRENT SILICON RECTIFIERS

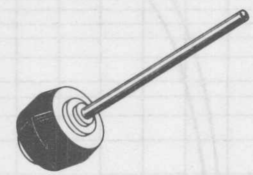
. . . compact, highly efficient silicon rectifiers for medium-current applications requiring:

- High Current Surge – 400 Amperes @ T_J = 175 °C
- Peak Performance @ Elevated Temperature – 25 Amperes @ T_C = 150 °C
- Low Cost
- Compact, Molded Package – For Optimum Efficiency in a Small Case Configuration.

MEDIUM-CURRENT SILICON RECTIFIERS

50 – 1000 VOLTS
25 AMPERES

DIFFUSED JUNCTION



MAXIMUM RATINGS

Characteristic	Symbol	TRA 0750	TRA 0751	TRA 0752	TRA 0754	TRA 0756	TRA 0758	TRA 0760	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 50 Hz peak)	V_{RSM}	60	120	240	480	720	960	1200	Volts
Average Rectified Forward Current (Single phase, resistive load, 50 Hz, T_C = 150 °C)	I_O	25							Amp
Non-Repetitive Peak Surge Current (surge applied @ rated Load conditions, half wave, single phase, 50 Hz)	I_{FSM}	400 (for 1 cycle)							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +175							°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case (Single Side Cooled)	$R_{\theta JC}$	1.0	°C/W

ELECTRICAL CHARACTERISTICS

Characteristics and Conditions	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage (I_F = 78.5 Amp, T_C = 25 °C)	V_F	1.18	Volts
Maximum Reverse Current (rated dc voltage) T_C = 25 °C T_C = 100 °C	I_R	 100 500	µA

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded.

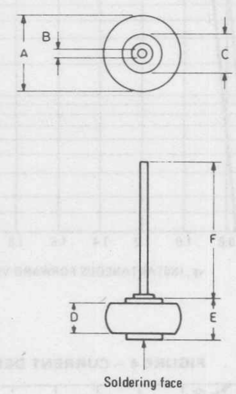
FINISH: All External Surfaces are Corrosion Resistant and the Contact Areas Readily Solderable.

POLARITY: Cathode to Soldering face. For Reverse polarity parts Add "R" Suffix. Ex: TRA0750R

MOUNTING POSITIONS: Any

MAXIMUM TEMPERATURE FOR SOLDERING PURPOSES: 190 °C

WEIGHT: 2,1 Grams (Approximately)



DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	0.395	0.405	10.03	10.29
B	0.050	0.053	1.27	1.35
C	0.218	0.222	5.54	5.64
D	0.165	0.175	4.19	4.45
E	0.234	0.246	5.94	6.25
F	0.990	1.010	25.15	25.65

CASE 195-01

FIGURE 1 — FORWARD VOLTAGE

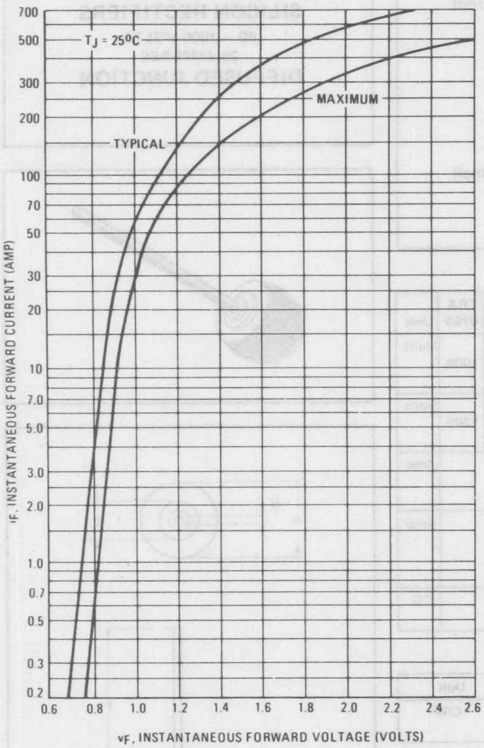


FIGURE 2 — NON-REPETITIVE SURGE CURRENT

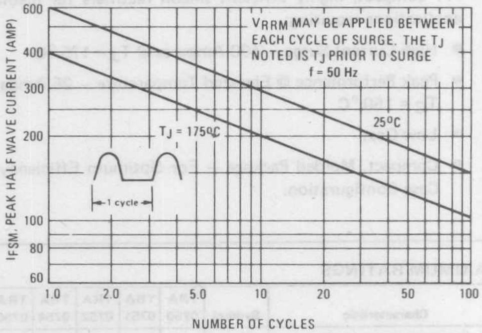


FIGURE 3 — FORWARD VOLTAGE TEMPERATURE COEFFICIENT

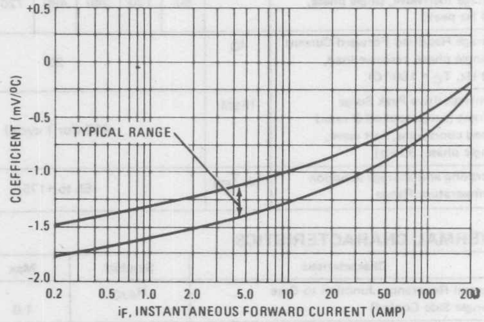


FIGURE 4 — CURRENT DERATING

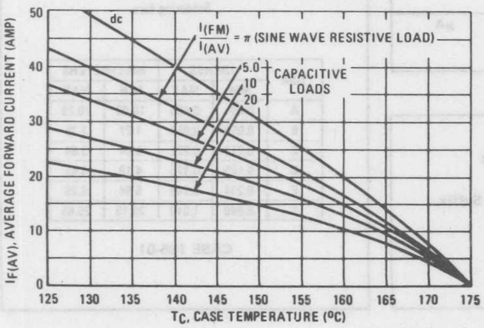


FIGURE 5 — FORWARD POWER DISSIPATION

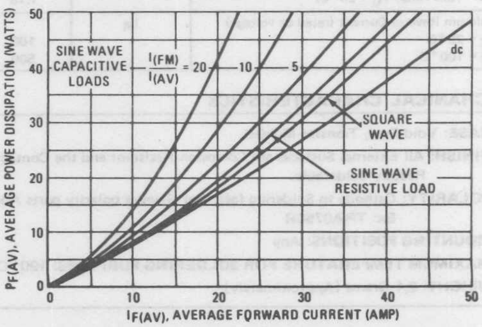
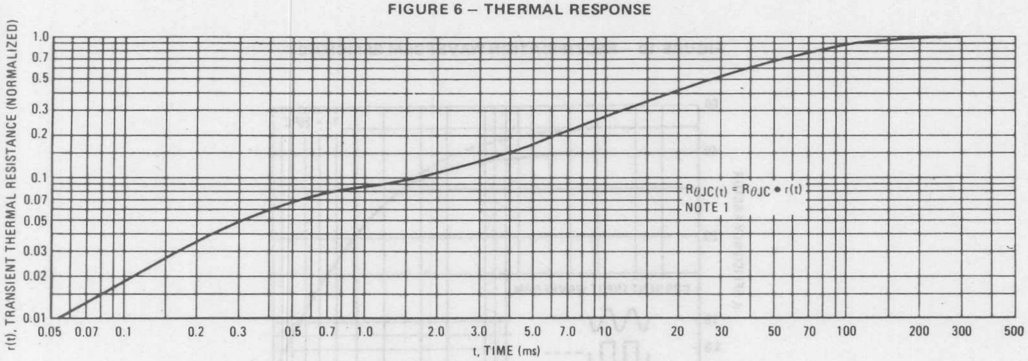
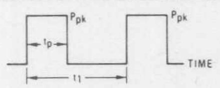


FIGURE 6 – THERMAL RESPONSE





DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.,

$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$.

FIGURE 7 – CAPACITANCE

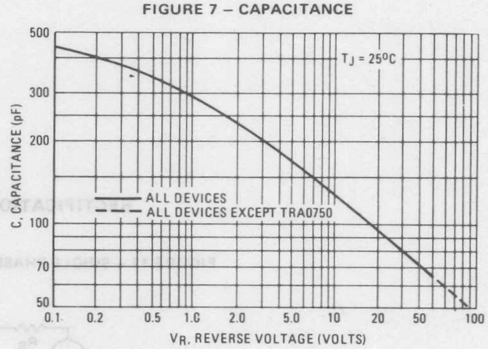


FIGURE 8 – FORWARD RECOVERY TIME

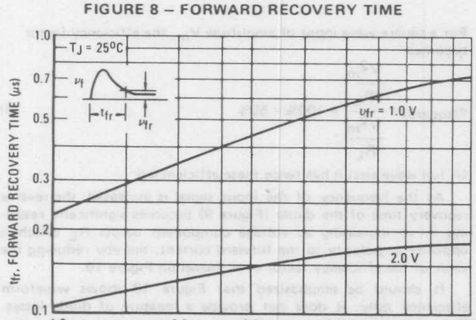


FIGURE 9 – REVERSE RECOVERY TIME

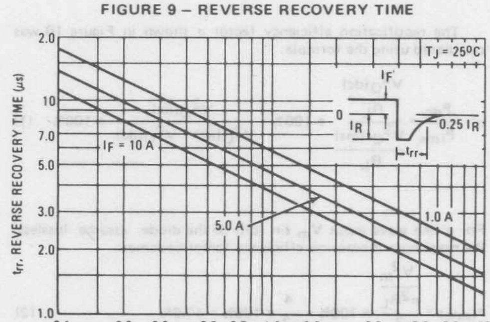
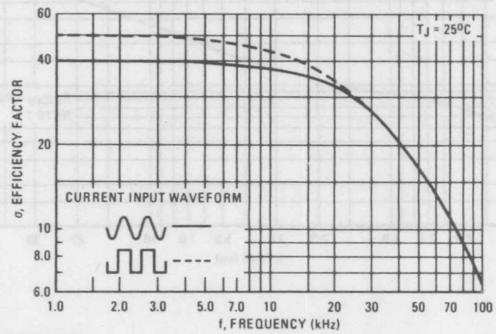
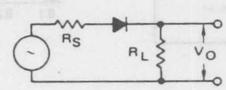


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY



RECTIFICATION EFFICIENCY NOTE

FIGURE 11 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\frac{V^2_{O(dc)}}{R_L}}{\frac{V^2_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2_{O(dc)}}{V^2_{O(ac)} + V^2_{O(dc)}} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin (\omega t)$ to the diode, assume lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\frac{V^2_m}{\pi^2 R_L}}{\frac{V^2_m}{4R_L}} \bullet 100\% = \frac{4}{\pi^2} \bullet 100\% = 40.6\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\frac{V^2_m}{2R_L}}{\frac{V^2_m}{R_L}} \bullet 100\% = 50\% \quad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 10.

It should be emphasized that Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_O with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

ASSEMBLY AND SOLDERING INFORMATION

There are *two basic areas* of consideration for successful implementation of button rectifiers:

1. Mounting and Handling
2. Soldering

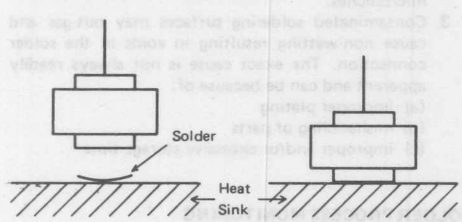
each should be carefully examined before attempting a finished assembly or mounting operation.

MOUNTING AND HANDLING

The button rectifier lends itself to a multitude of assembly arrangements but one key consideration must *always* be included:

One Side of the Connections to the Button Must Remain Flexible!

TYPICAL ASSEMBLY ARRANGEMENT



The base heat sink may be of various materials whose shape and size are a function of the individual application and the heat transfer requirements.

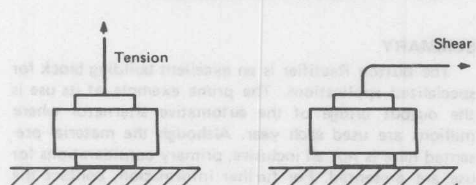
Common	Heat Sink Materials
Steel	Tin or Nickel Plated
Copper	Raw or Tin, Nickel Plated
Aluminium	Tin or Nickel Plated

Handling of the button during assembly must be relatively gentle to minimize sharp impact shocks and avoid nicking of the plastic. Improperly designed automatic handling equipment is the worst source of unnecessary shocks. Techniques for vacuum handling and spring loading should be investigated.

The mechanical stress limits for the button diode are as follows:

Tension	14,5	DaN
Shear	25	DaN

MECHANICAL STRESS



Exceeding these recommended maximums can result in electrical degradation of the device.

SOLDERING

The button rectifier is basically a semiconductor chip bonded between two nickel-plated copper heat sinks with an encapsulating material of thermal-setting silicone. The exposed metal areas are also tin plated to enhance solderability.

In the soldering process it is important that the temperature not exceed 190 °C if device damage is to be avoided. Various solder alloys can be used for this operation but one type is recommended for best results: 63% tin, 37% lead; Melting point 183 °C (eutetic).

Solder is available as preforms or paste. The paste contains both the metal and flux and can be dispensed rapidly. The solder preform requires the application of a flux to assure good wetting of the solder. The type of flux used depends upon the degree of cleaning to be accomplished and is a function of the metals involved. These fluxes range from a mild rosin to a strong acid; e.g., Nickel plating oxides are best removed by an acid base flux while an activated rosin flux may be sufficient for tin plated parts.

Since the button is relatively light-weight, there is a tendency for it to float when the solder becomes liquid. To prevent bad joints and misalignment it is suggested that a weighting or spring loaded fixture be employed. It is also important that severe thermal shock (either heating or cooling) be avoided as it may lead to damage of the die or encapsulant of the part.

Button holding fixtures for use during soldering may be of various materials. Stainless steel has a longer use life while black anodized aluminum is less expensive and will limit heat reflection and enhance absorption. The assembly volume will influence the choice of materials. Fixture dimension tolerances for locating the button must allow for expansion during soldering as well as allowing for button clearance.

HEATING TECHNIQUES

The following four heating methods have their advantages and disadvantages depending on volume of buttons to be soldered.

1. **Belt Furnaces** readily handle large or small volumes and are adaptable to establishment of "on-line" assembly since a variable belt speed sets the run rate. Individual furnace zone controls make excellent temperature control possible. Cost ranges from $20,000 to $30,000.
2. **Flame Soldering** involves the directing of natural gas flame jets at the base of a heatsink as the heatsink is indexed to various loading-heating-cooling-unloading positions. This is the most economical labor method of soldering large volumes. Flame soldering offers good temperature control but requires sophisticated temperature monitoring systems such as infrared. Cost ranges from $25,000 to $40,000.

ASSEMBLY AND SOLDERING INFORMATION (continued)

3. **Ovens** are good for batch soldering and are production limited. There are handling problems because of slow cooling. Response time is load dependent, being a function of the watt rating of the oven and the mass of parts. Large ovens may not give an acceptable temperature gradient. Capital cost is low compared to belt furnaces and flame soldering.
4. **Hot Plates** are good for soldering small quantities of prototype devices. Temperature control is fair with overshoot common because of the exposed heating surface. Solder flow and positioning can be corrected during soldering since the assembly is exposed. Investment cost is very low.

Regardless of the heating method used, a soldering profile giving the time-temperature relationship of the particular method must be determined to assure proper soldering. Profiling must be performed on a scheduled basis to minimize poor soldering. The time-temperature relationship will change depending on the heating method used.

SOLDER PROCESS EVALUATION

Characteristics to look for when setting up the soldering process:

I **Overtemperature** is indicated by any one or all three of the following observations.

1. Remelting of the solder inside the button rectifier shows the temperature has exceeded 285^{O}C and is noted by "islands" of shiny solder and solder dewetting when a unit is broken apart.
2. Cracked die inside the button may be observed by a moving reverse oscilloscope trace when pressure is applied to the unit.
3. Cracked plastic may be caused by thermal shock as well as overtemperature so cooling rate should also be checked.

II **Cold soldering** gives a grainy appearance and solder build-up without a smooth continuous solder fillet. The temperature must be adjusted until the proper solder fillet is obtained within the maximum temperature limits.

III **Incomplete solder fillets** result from insufficient solder or parts not making proper contact.

IV **Tilted buttons** can cause a void in the solder between the heatsink and button rectifier which will result in poor heat transfer during operation. An eight degree tilt is a suggested maximum value.

V **Plating problems** require a knowledge of plating operations for complete understanding of observed deficiencies.

1. Peeling or plating separation is generally seen when a button is broken away for solder inspection. If heatsink or terminal base metal is present the plating is poor and must be corrected.
2. Thin plating allows the solder to penetrate through to the base metal and can give a poor connection. A suggested minimum plating thickness is 300 microinches.
3. Contaminated soldering surfaces may out-gas and cause non-wetting resulting in voids in the solder connection. The exact cause is not always readily apparent and can be because of:
   (a) improper plating
   (b) mishandling of parts
   (c) improper and/or excessive storage time

SOLDER PROCESS MONITORING

Continuous monitoring of the soldering process must be established to minimize potential problems. All parts used in the soldering operation should be sampled on a lot by lot basis by assembly of a controlled sample. Evaluate the control sample by break-apart tests to view the solder connections, by physical strength tests and by dimensional characteristics for part mating.

A shear test is a suggested way of testing the solder bond strength.

POST SOLDERING OPERATION CONSIDERATIONS

After soldering, the completed assembly must be unloaded, washed and inspected.

Unloading must be done carefully to avoid unnecessary stress. Assembly fixtures should be cooled to room temperature so solder profiles are not affected.

Washing is mandatory if an acid flux is used because of its ionic and corrosive nature. Wash the assemblies in agitated hot water and detergent for three to ten minutes. After washing; rinse, blow off excessive water and bake one hour at 150 °C to remove trapped moisture.

Inspection should be both electrical and physical. Any rejects can be reworked as required.

SUMMARY

The Button Rectifier is an excellent building block for specialized applications. The prime example of its use is the output bridge of the automative alternator where millions are used each year. Although the material presented here is not all inclusive, primary considerations for use are presented. For further information, contact the nearest Motorola Sales Office or franchised distributor.

MOTOROLA

TRA 1102 SERIES

MEDIUM CURRENT SILICON RECTIFIERS

. . . utilizing a MR 2500 button type Rectifier inserted into a copper package, providing all its performances and reliability. Highly efficient for applications requiring:

- High Current Surge — 400 Amperes at Tj = 175°C
- Peak Performance at Elevated Temperature — 35 A at Tc = 120°C
- Low Cost

MEDIUM-CURRENT SILICON RECTIFIERS

30–1100 VOLTS
35 AMPERES
DIFFUSED JUNCTION

MAXIMUM RATINGS

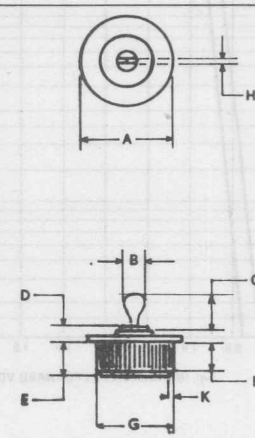
Rating	Symbol	TRA 1102	TRA 1105	TRA 1110	TRA 1120	TRA 1130	TRA 1140	TRA 4360	Units
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	30	75	150	300	450	600	1100	Volts
Non Repetitive Peak Reverse Voltage (half wave, single phase, 50 Hz peak)	V_{RSM}	40	100	200	360	540	720	1300	Volts
Average Rectified Forward Current (single phase, resistive load, 50 Hz, TC = 120°C)	I_O	35							A
Non Repetitive Peak Surge Current (surge applied at rated load conditions, half wave, single phase, 50 Hz)	I_{FSM}	400 (for 1 cycle)							A
I^2t Rating (non repetitive, for t greater than 1 ms and less than 10 ms	I^2t	800							A^2s (ms)
Operating and Storage Junction Temperature Range	Tj, Tstg	– 65 to + 175							°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case (Single Side Cooled)	$R_{\theta JC}$	1.0	°C/W

ELECTRICAL CHARACTERISTICS

Characteristics and Conditions	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage (i_F = 78.5 Amp, T_C = 25°C)	v_F	1.18	Volts
Maximum Reverse Current (rated dc voltage) T_C = 25°C T_C = 100°C	I_R	 100 500	µA



DIM	MILLIMETERS MIN.	MILLIMETERS MAX.	INCHES MIN.	INCHES MAX.
A	15.75	16.00	0.620	0.630
B		4.00		0.158
C		7.50		0.295
D	1.95	2.10	0.0768	0.0827
E	6.02	6.68	0.237	0.263
F	5.08	-	0.200	-
G	12.725	12.827	0.501	0.505
H	0.69	0.71	0.0271	0.0279
K	0.38	0.89	0.0149	0.0350

CASE: 043–06

CASE: Void Free, Transfer Molded Button inserted into a Copper frame

FINISH: All External Surfaces are Corrosion Resistant and the Contact Areas Readily Solderable

POLARITY: Cathode to case, for Reverse polarity parts, add „R" suffix. Ex : TRA 1102 R

CENTRAL TERMINAL: Upon special request any terminal can be welded on it.

MAXIMUM TEMPERATURE FOR SOLDERING PURPOSES: 190°C

FIGURE 1 – FORWARD VOLTAGE

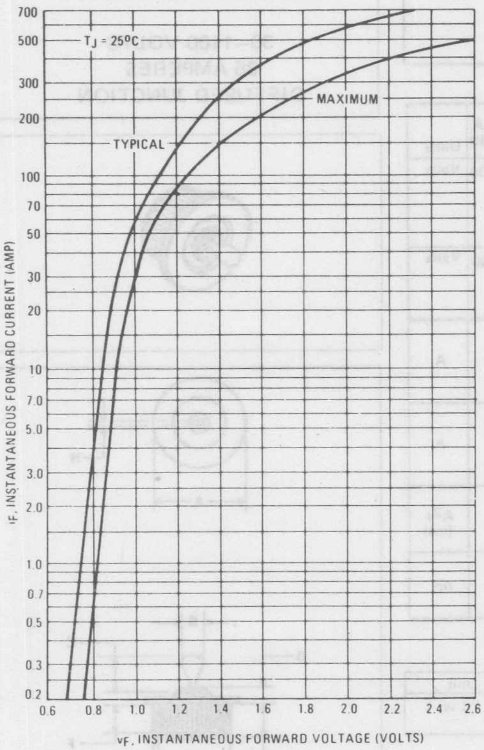


FIGURE 2 – NON-REPETITIVE SURGE CURRENT

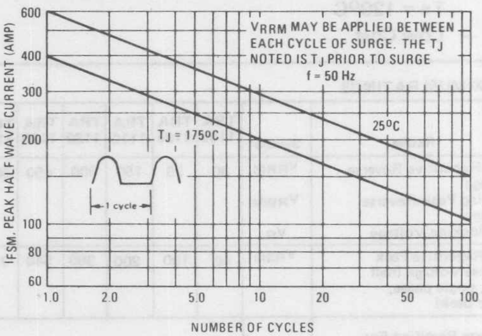


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

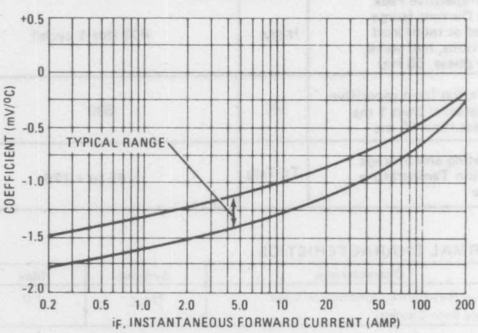


FIGURE 4 – CURRENT DERATING

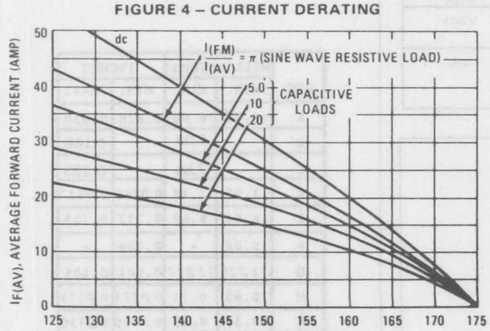


FIGURE 5 – FORWARD POWER DISSIPATION

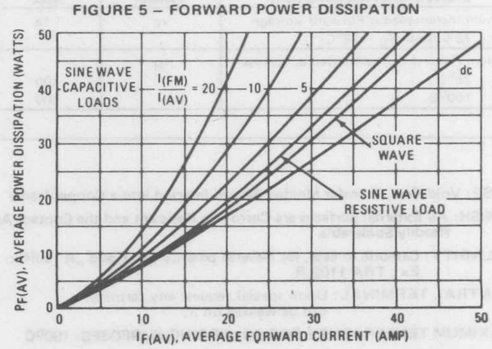
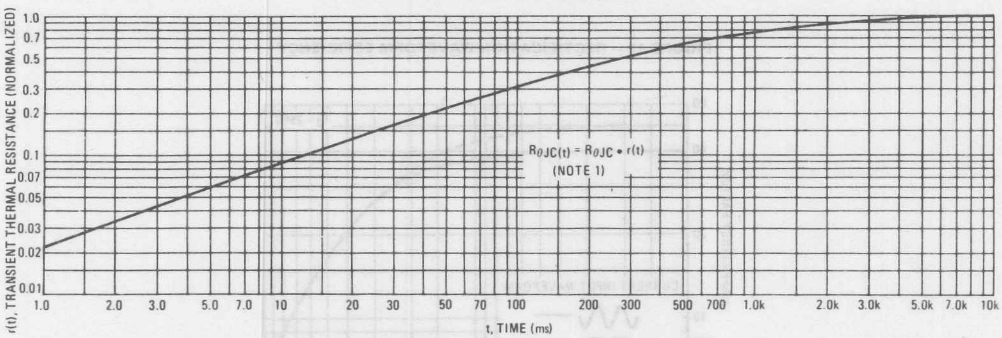
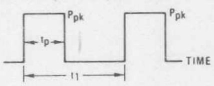


FIGURE 6 – THERMAL RESPONSE





DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse.

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.,
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

FIGURE 7 – CAPACITANCE

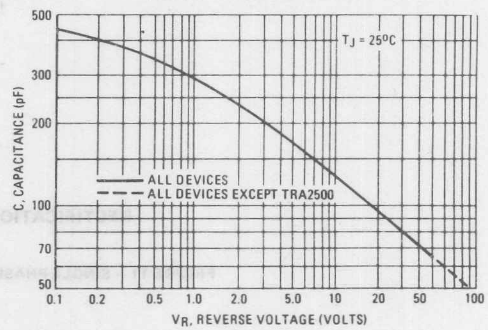


FIGURE 8 – FORWARD RECOVERY TIME

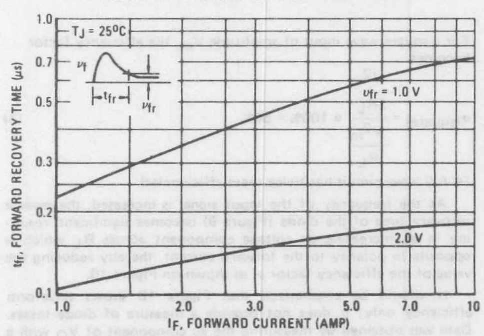


FIGURE 9 – REVERSE RECOVERY TIME

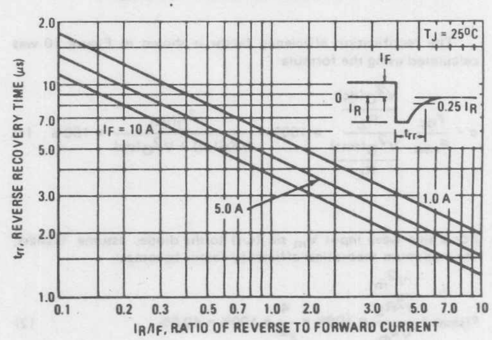
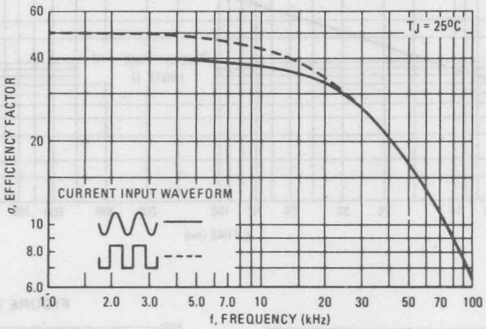
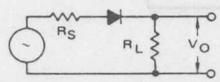


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY



RECTIFICATION EFFICIENCY NOTE

FIGURE 11 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\frac{V^2{}_{O(dc)}}{R_L}}{\frac{V^2{}_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2{}_{O(dc)}}{V^2{}_{O(ac)} + V^2{}_{O(dc)}} \bullet 100\% \quad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assume lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\frac{V^2{}_m}{\pi^2 R_L}}{\frac{V^2{}_m}{4R_L}} \bullet 100\% = \frac{4}{\pi^2} \bullet 100\% = 40.6\% \quad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\frac{V^2{}_m}{2R_L}}{\frac{V^2{}_m}{R_L}} \bullet 100\% = 50\% \quad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 10.

It should be emphasized that Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_O with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

MOUNTING

Motorola' TRA1102 Series rectifiers are designed for press-fitted mounting in a heat sink. Recommended procedures for this type of mounting are as follows:

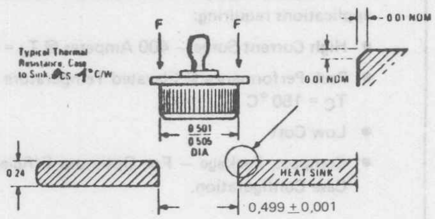
1. Drill a hole in the heat sink 0.499 ± 0.001 inch in diameter.
2. Break the hole edge as shown to prevent shearing off the knurled edge of the rectifier when it is pressed into the hole.
3. The depth of the break should be 0.010 inch maximum to retain maximum heat sink surface contact with the knurled rectifier surface.
4. Width of the break should be 0.010 inch as shown.

These procedures will allow proper entry of the rectifier knurled surface, provide good rectifier-heat sink surface contact, and assure reliable rectifier operation. If the break is made too deep, thereby reducing contact area for heat transfer, reliability of operation will be impaired.

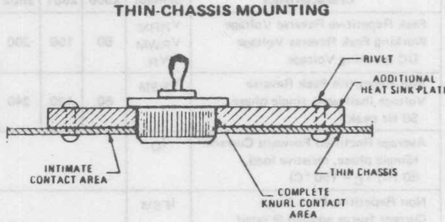
These devices can be mounted in a thin chassis by inserting the rectifier through an additional heat sink plate which is mounted in intimate contact with the upper side of the chassis. This provides additional contact area for the rectifier knurled edge, as well as additional heat sink capacity.

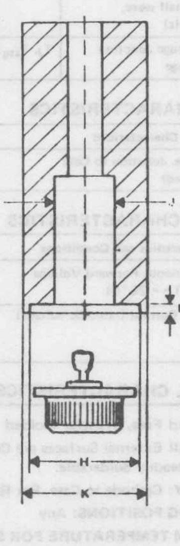
5. The pressing force will vary from 250 lbs (115 daN) to 1000 lbs (454 daN), depending on the heat sink material used.
6. Pressing force must be appliedby a tool hereunder described:

HEAT SINK MOUNTING



THIN-CHASSIS MOUNTING





DIM	MILLIMETERS MIN.	MILLIMETERS MAX.	INCHES MIN.	INCHES MAX.
H	15.75	16.00	0.620	0.630
J	9.14	9.38	0.360	0.370
K	17.8	18.2	0.700	0.716
L	1.0	1.2	0.039	0.047

![Motorola logo] **MOTOROLA**

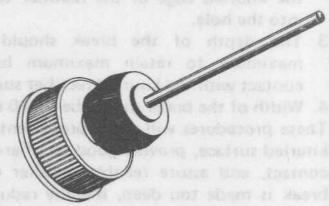
TRA 2500 SERIES

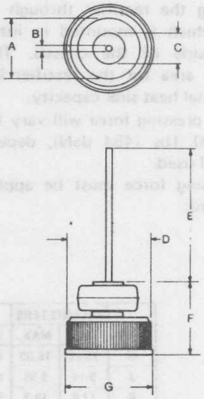
MEDIUM-CURRENT SILICON RECTIFIERS

. . . compact, highly efficient silicon rectifiers for medium-current applications requiring:

- High Current Surge – 400 Amperes @ T_J = 175 °C
- Peak Performance @ Elevated Temperature – 25 Amperes @ T_C = 150 °C
- Low Cost
- Compact, Package – For Optimum Efficiency in a Small Case Configuration.

MEDIUM-CURRENT SILICON RECTIFIERS
50 – 1000 VOLTS
25 AMPERES
DIFFUSED JUNCTION





DIM	INCHES MIN	INCHES MAX	MILLIMETERS MIN	MILLIMETERS MAX
A	0.395	0.405	10.03	10.29
B	0.050	0.053	1.27	1.35
C	0.218	0.222	5.54	5.64
D	0.499	0.504	12.67	12.82
E	0.990	1.010	25.15	25.65
F	0.463	0.427	11.75	10.85
G	0.501	0.505	12.72	12.83

CASE 273-01

MAXIMUM RATINGS

Characteristics	Symbol	TRA 2500	TRA 2501	TRA 2502	TRA 2504	TRA 2506	TRA 2508	TRA 2510	Unit
Peak Repetitive Reverse Voltage Working Peak Reverse Voltage DC Blocking Voltage	V_{RRM} V_{RWM} V_R	50	100	200	400	600	800	1000	Volts
Non-Repetitive Peak Reverse Voltage (halfwave, single phase, 50 Hz peak)	V_{RSM}	60	120	240	480	720	960	1200	Volts
Average Rectified Forward Current (Single phase, resistive load, 50 Hz, T_C = 150 °C)	I_O	25							Amp
Non-Repetitive Peak Surge Current (surge applied @ rated load conditions, half wave, single phase, 50 Hz)	I_{FSM}	400 (for 1 cycle)							Amp
Operating and Storage Junction Temperature Range	T_J, T_{stg}	-65 to +175							°C

THERMAL CHARACTERISTICS

Characteristic	Symbol	Max	Unit
Thermal Resistance, Junction to Case (Single Side Cooled)	$R_{\theta JC}$	1.0	°C/W

ELECTRICAL CHARACTERISTICS

Characteristics and Conditions	Symbol	Max	Unit
Maximum Instantaneous Forward Voltage (I_F = 78.5 Amp, T_C = 25 °C)	v_F	1.18	Volts
Maximum Reverse Current (rated dc voltage) T_C = 25 °C T_C = 100 °C	I_R	 100 500	µA

MECHANICAL CHARACTERISTICS

CASE: Void Free, Transfer Molded Package soldered on copper Slug.

FINISH: All External Surfaces are Corrosion Resistant and the Contact Areas Readily Solderable.

POLARITY: Cathode to Case. For Reverse Version, add "R" Suffix.

MOUNTING POSITIONS: Any

MAXIMUM TEMPERATURE FOR SOLDERING PURPOSES: 190 °C

WEIGHT: 7.5 Grams (Approximately)

E-104

FIGURE 1 – FORWARD VOLTAGE

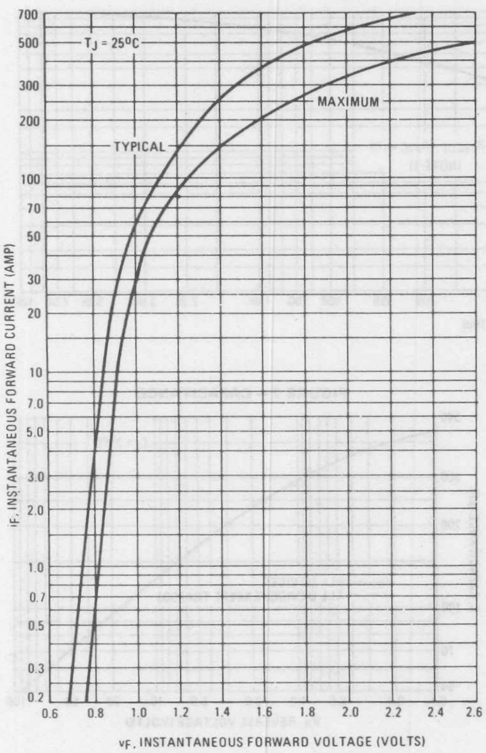


FIGURE 2 – NON-REPETITIVE SURGE CURRENT

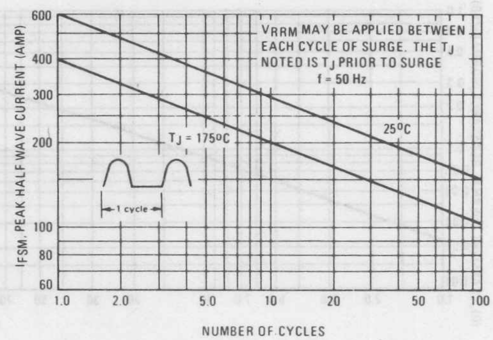


FIGURE 3 – FORWARD VOLTAGE TEMPERATURE COEFFICIENT

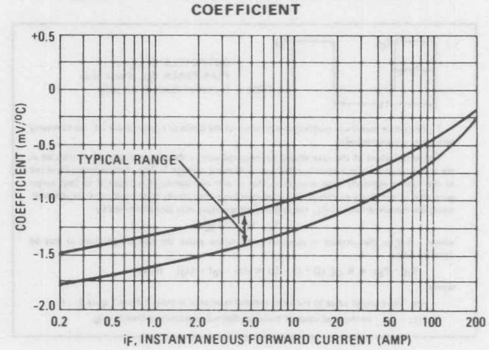


FIGURE 4 – CURRENT DERATING

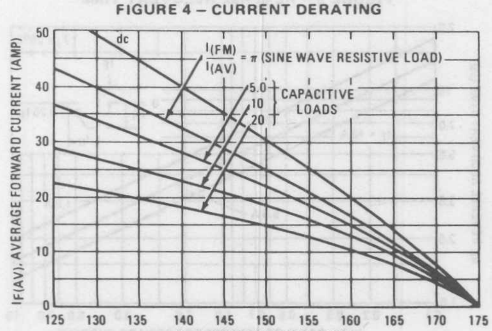


FIGURE 5 – FORWARD POWER DISSIPATION

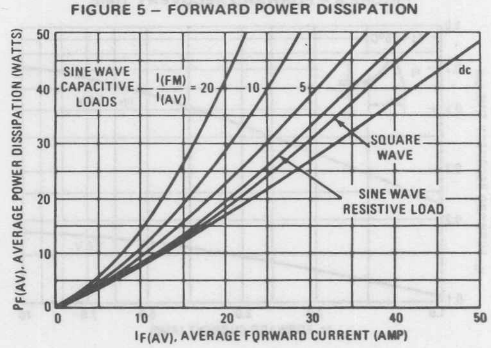
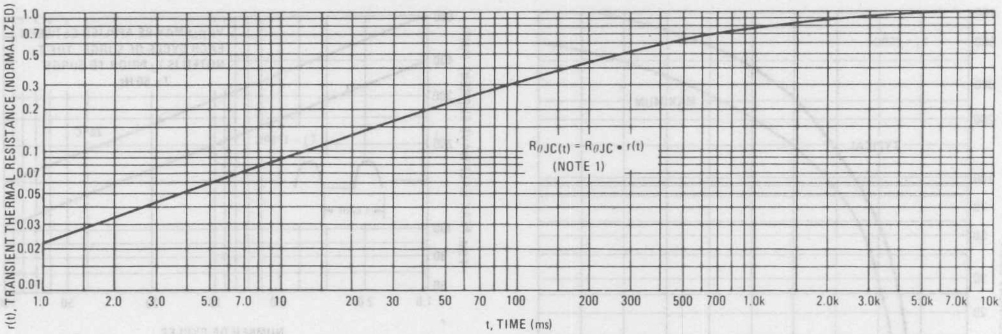
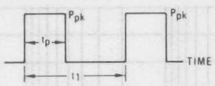


FIGURE 6 – THERMAL RESPONSE





DUTY CYCLE, $D = t_p/t_1$
PEAK POWER, P_{pk}, is peak of an equivalent square power pulse

To determine maximum junction temperature of the diode in a given situation, the following procedure is recommended.

The temperature of the case should be measured using a thermocouple placed on the case at the temperature reference point (see the outline drawing on page 1). The thermal mass connected to the case is normally large enough so that it will not significantly respond to heat surges generated in the diode as a result of pulsed operation once steady state conditions are achieved. Using the measured value of T_C, the junction temperature may be determined by

$$T_J = T_C + \Delta T_{JC}$$

where ΔT_{JC} is the increase in junction temperature above the case temperature. It may be determined by

$$\Delta T_{JC} = P_{pk} \bullet R_{\theta JC} [D + (1 - D) \bullet r(t_1 + t_p) + r(t_p) - r(t_1)]$$

where

$r(t)$ = normalized value of transient thermal resistance at time, t, from Figure 6, i.e.,
$r(t_1 + t_p)$ = normalized value of transient thermal resistance at time $t_1 + t_p$

FIGURE 7 – CAPACITANCE

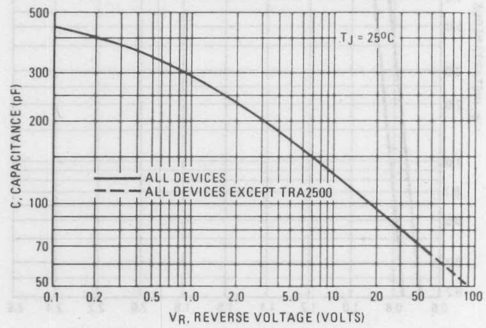


FIGURE 8 – FORWARD RECOVERY TIME

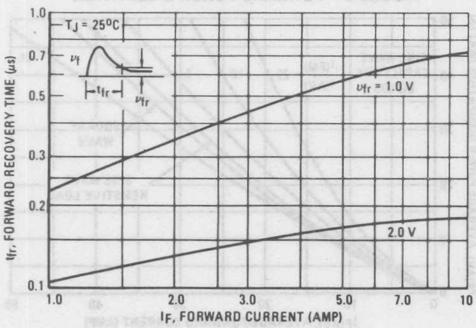


FIGURE 9 – REVERSE RECOVERY TIME

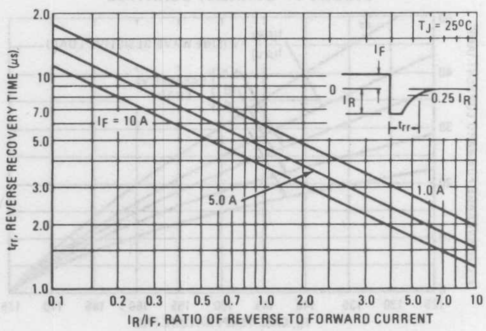
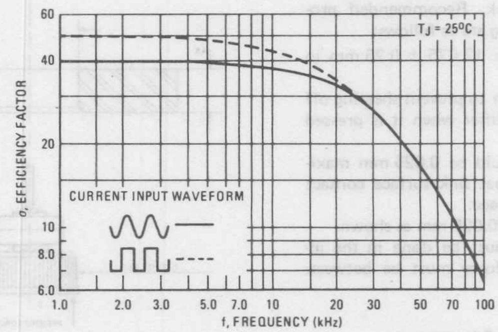
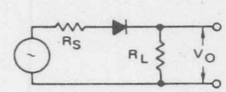


FIGURE 10 – RECTIFICATION WAVEFORM EFFICIENCY



RECTIFICATION EFFICIENCY NOTE

FIGURE 11 – SINGLE-PHASE HALF-WAVE RECTIFIER CIRCUIT



The rectification efficiency factor σ shown in Figure 10 was calculated using the formula:

$$\sigma = \frac{P_{dc}}{P_{rms}} = \frac{\dfrac{V^2{}_{O(dc)}}{R_L}}{\dfrac{V^2{}_{O(rms)}}{R_L}} \bullet 100\% = \frac{V^2{}_{O(dc)}}{V^2{}_{O(ac)} + V^2{}_{O(dc)}} \bullet 100\% \qquad (1)$$

For a sine wave input $V_m \sin(\omega t)$ to the diode, assume lossless, the maximum theoretical efficiency factor becomes:

$$\sigma_{(sine)} = \frac{\dfrac{V^2{}_m}{\pi^2 R_L}}{\dfrac{V^2{}_m}{4R_L}} \bullet 100\% = \frac{4}{\pi^2} \bullet 100\% = 40.6\% \qquad (2)$$

For a square wave input of amplitude V_m, the efficiency factor becomes:

$$\sigma_{(square)} = \frac{\dfrac{V^2{}_m}{2R_L}}{\dfrac{V^2{}_m}{R_L}} \bullet 100\% = 50\% \qquad (3)$$

(A full wave circuit has twice these efficiencies)

As the frequency of the input signal is increased, the reverse recovery time of the diode (Figure 9) becomes significant, resulting in an increasing ac voltage component across R_L which is opposite in polarity to the forward current, thereby reducing the value of the efficiency factor σ, as shown on Figure 10.

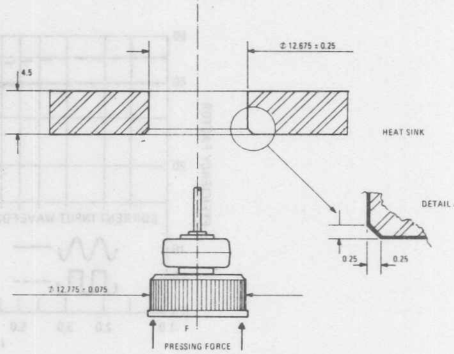
It should be emphasized that Figure 10 shows waveform efficiency only; it does not provide a measure of diode losses. Data was obtained by measuring the ac component of V_O with a true rms ac voltmeter and the dc component with a dc voltmeter. The data was used in Equation 1 to obtain points for Figure 10.

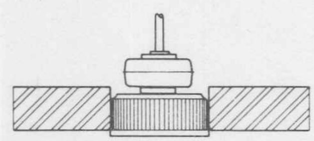
MOUNTING INSTRUCTIONS

Motorola TRA2500 rectifiers are designed for press-fitted mounting in a heat sink. Recommended procedures for this type of mounting are as follows:

1. Drill a hole in the heat sink 12.675 ± 0.25 mm in diameter.
2. Break the hole edge as shown to prevent shearing off the knurled edge of the rectifier when it is pressed into the hole.
3. The depth of the break should be 0.025 mm maximum to retain maximum heat sink surface contact with the knurled rectifier surface.
4. Width of the break should be 0.025 mm as shown.
5. Introduction and pressing must be done in the indicated direction. Pressing force must be between 115 daN and 454 daN.

Note: Heat sink material:
- Copper – Max. 50 Rockwell F Hardness
- Aluminium – Max. 65 Brinell Hardness
  Min. Thickness 4.5 mm





CHAPTER 18: ALPHANUMERIC INDEX

NOTES